RMS
File

INTERIM REPORT NO. 2

REVIEW AND MODIFICATION OF RESILIENT MODULUS TEST PROCEDURES AND APPARATUS

ITD - RP097 - INT(2)

to

IDAHO TRANSPORTATION DEPARTMENT
DIVISION OF HIGHWAYS
P.O. Box 7129
Boise, Idaho 83707

F.C. Register No. 80-030

by

James H. Hardcastle
Associate Professor of Civil Engineering

and

Robert P. Lottman
Professor of Civil Engineering

COLLEGE OF ENGINEERING
UNIVERSITY OF IDAHO
Moscow, Idaho 83843

June 30, 1981

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The purpose of this second interim report is to describe briefly the work completed on the project during the period September 1, 1980, to June 30, 1981. Work performed during this period was part of Phase Two of the project and included the following tasks: (1) Test Equipment Development, (2) Test Equipment and Procedure Evaluation, and (3) Develop Comparative Test Plan. This report also contains an updated summary of the responses to the survey questionnaire on current resilient modulus testing practices. As in the previous interim report, the emphasis in this report is on resilient modulus testing of subgrade soils.

II. CURRENT PRACTICES IN RESILIENCE TESTING

As part of the survey of current practice in resilient modulus testing, a survey questionnaire was prepared and distributed to 54 pavement design organizations, including the 50 state highway agencies. Copies of the questionnaire and cover letter were included in the previous interim report for this project (1)[1].

Table 1 contains a summary of the questionnaire responses received through June 15, 1981. The table indicates that 13 states of the 46 responding to the questionnaire use some type of resilient modulus test for pavement materials. Twelve states conduct tests on asphalt bound materials. Eleven of the states testing asphalt mixes use the indirect diametral tension method developed by Schmidt (2) and one state uses a uniaxial cyclic compression test conducted on

---

[1]Numbers in parentheses refer to references given at the end of this report.

Table 1. Preliminary Summary of Questionnaire Responses

Agency	Response Received	Application of Laboratory M_R Tests: Not Used	Subgrades and Unbound Granular	Stabilized Materials: Asphalt Mixes	Stabilized Materials: Other
Alabama	X	X			
Alaska[1]	X	X			
Arizona[2]	X			X	
Arkansas	X	X			
California	X		X	X	
Colorado[2]	X			X	
Connecticut	X	X			
Delaware	X	X			
District of Columbia					
Florida[2]	X		X	X	X
Georgia[2]	X		X	X	
Hawaii	X	X			
Idaho[2]	X		X		
Illinois	X	X			
Indiana	X	X			
Iowa	X	X			
Kansas	X	X			
Kentucky	X		X	X	X
Louisiana	X			X	X
Maine	X	X			
Maryland	X	X			
Massachusetts	X	X			
Michigan[2]	X		X	X	
Minnesota[1]	X	X			
Mississippi	X	X			
Missouri	X	X			
Montana[2]	X			X	
Nebraska	X	X			
Nevada	X	X			
New Hampshire	X	X			

Table 1. Continued

		Application of Laboratory M_R Tests			
	Response Received	Not Used	Subgrades and Unbound Granular	Stabilized Materials	
				Asphalt Mixes	Other
New Jersey	X	X			
New Mexico	X	X			
New York	X	X			
North Carolina	X	X			
North Dakota	X	X			
Ohio					
Oklahoma	X	X			
Oregon					
Pennsylvania	X	X			
Puerto Rico					
Rhode Island	X	X			
South Carolina	X	X			
South Dakota	X	X			
Tennessee	X	X			
Texas[2]	X			X	
Utah[2]	X		X	X	
Vermont	X	X			
Virginia	X	X			
Washington[2]	X			X	
West Virginia					
Wisconsin					
Wyoming	X	X			
New Brunswick	X	X			
Ontario	X	X			

1. Agencies not presently using resilient modulus but which plan to in the future.
2. Agencies indicating willingness to participate in cooperative study.

unconfined cyclindrical specimens. All states testing asphalt bound materials measure resilient modulus, M_R, and not complex modulus, E*. Table 2 summarizes the questionnaire responses relating to test parameters for resilient modulus of asphalt mixes.

Six of the 12 states conducting resilient modulus tests on asphalt mixes indicated that they also test subgrade soils or unbound select granular materials. Idaho is the only state which tests subgrade soils but does not test asphalt bound materials. Table 3 summarizes the responses concerning resilient modulus tests on soils and Table 4 summarizes the responses for unbound select granular materials.

No completely general trends with regard to test specimen dimensions, preparation methods, densities, water contents, stress level and test equipment are apparent from the questionnaire responses for subgrade soils and unbound select granular materials. Perhaps the most significant result from the questionnaire responses is that so few states are using resilient modulus to characterize subgrade materials. Of those states which are using resilient modulus for soils, only four (Florida, Georgia, Idaho and Utah) indicated a willingness to participate in a cooperative reproducibility study.

III. TEST EQUIPMENT DEVELOPMENT (Task 5)

Work that was to have been completed in Task 5 consisted of the design and construction of modifications to the Idaho Transportation Department's resilient modulus apparatus. Based on information obtained in the literature review, survey questionnaire, and in contacts with other users of resilient modulus test apparatus, two general design approaches utilizing pneumatic cylinders

Table 2. Summary of Questionnaire Responses Concerning Asphalt Bound Materials

State	Willing to Participate in Coop Study	Mixes Tested			Temperatures	Method of Test		Sample Dimensions, inches	
		A.C.[1]	A.E.[2]	Other	°F	IDT[3]	UC[4]	Diameter	Length
Arizona	YES	X	X	X	73	X	X	4.0	2.5
California	NO	X			77	X		4.0	2.5
Colorado	YES	X	X	X	77	X		4.0	2.5
Florida	YES	X			41, 77, 85, 104	X	X[5]	4.0	8.0
Georgia	YES	X			Room	X		4.0	2.5
Kentucky	NO	X			40, 77, 100		X	2.8	7.0
Louisana	NO	X			70	X		4.0	2.5
Michigan	NO	X			20, 39.2, 77	X		4.0	2.0-4.0
Montana	YES	X			55, 73	X		4.0	2.5
Texas	YES	X			Room	X		4.0	2.5
Utah	YES	X			-20 to 140	X		4.0	2.5
Washington	YES	X			Room	X		4.0	1.0-2.5

[1]Asphalt concrete surfaces and bases
[2]Asphalt emulsions
[3]Indirect diametral tension
[4]Unconfined compression
[5]Also use beam flexure

Table 3. Summary of Questionnaire Responses Concerning Subgrade

State	Willing to Participate in Coop Study	Dimensions inches		Compaction (Note 1)	Dry Density (Note 2)	Water Content	σ_3 psi	σ_d psi	Load Pulse sec.	Freq cpm	Load Device (Note 3)
		Diam.	Length								
California	NO	4	8	S, K	Calif. 216	Varys	1-20	1-80	0.1	20	B
Florida	YES	4	8	K	in-situ	in-situ	3-20	3-60	0.1	60	MTS
Georgia	YES	2.8	5.6	S	95 T-99	opt	5	5-20	0.1	30	B
Idaho	YES	4	5	S, K	100 T-99	opt	1-3	0.5-10	0.2	30	B
Kentucky	NO	2.8	7	I	95 T-180	opt	5-15	2-10	1.0	30	B
Michigan	NO	2-6	4-11	I, K	100 T-99	opt	-	-	-	-	MTS
Utah	YES	4	6	I	-	opt	3	9	0.1	60	MTS

Note 1. I = impact, K = kneading, S = static

Note 2. Numbers are precentages of the maximum dry density obtainable using the designated AASHTO method

Note 3. B = Bellofram pneumatic piston, MTS = closed-loop servo-controlled hydraulic system

Table 4. Summary of Questionnaire Responses Concerning Unbound Select Granular Materials.

State	Specimen Dimensions Inches		Compaction Method	Dry Density	Water Content	$\hat{\sigma}_3$ psi	$\hat{\sigma}_d$ psi
	Diam.	Length	(Note 1)	(Note 2)			
Florida	4	8	K	"in-situ"	"in-situ"	5-20	3-60
Georgia	6	12	I	100 T-180	opt	5	10-40
Kentucky	2.8	7.0	I	95 T-180	opt	5-15	10-30
Michigan	4 or 6	8 or 11	I, K	100 T-99	opt	-	-
Utah	4	6	I	-	opt	3	9

Note 1. I = impact, K = kneading

Note 2. Numbers are percentages of maximum dry densities obtainable using the designated AASHTO method.

(Bellofram) as the loading device have been selected. However, in order to provide the department with the opportunity to review equipment alternatives prior to the expenditure of project capital outlay funds, complete, different prototype units of the suggested alternatives have not yet been assembled. Rather, evaluations of the components as well as production testing utilizing components similar to those contained in the suggested alternatives described below have been completed in the University of Idaho and other laboratories.

Costs for the principal subsystems which make up the suggested alternative test equipment assemblies are shown in Table 5. The table shows costs of the individual assemblies necessary to conduct resilient modulus tests on each of the three general types of materials used in flexible pavements; i.e., subgrade soils, unbound select granular materials (e.g., aggregate bases and subbases), and asphalt tested materials (surfacing and asphalt treated base), as well as the estimated cost of a single "complete" assembly for testing all three types of materials. The table contains costs of the alternatives with and without signal conditioning and recording equipment. Tables 6, 7, 8, and 9 list the costs of the component parts of the subsystems that make up the four resilient modulus test assemblies.

It should be noted that the costs listed in the various tables are for the resilient modulus test assemblies only and do not include the costs of apparatus necessary to prepare and condition the test specimens. It is expected that most of the test specimen preparation and any non-load related test specimen conditioning equipment (like that listed for subgrade soils in Table 10) is already available in the ITD Boise Materials Laboratory.

Table 5. Resilient Modulus Test Apparatus Subsystem Costs

Subsystem	Costs for Materials Capability, Dollars			
	Subgrade Soils	Unbound Select Granular	Asphalt Treated	Complete
Load Frame (Platform)	500	500	400	700
Load Actuator and Supports	405	475	385	1,205
Pneumatic Control	960	960	645	960
Test Specimen Mounting	1,500	2,000	25	2,205
Test Specimen Response	1,150	1,200	1,400	2,200
Subtotals for 5 Subsystems	4,515	5,135	2,555	7,090
Signal Conditioning and Recording	5,000	5,000	5,000	5,000
Total Resilient Modulus Test System	9,515	10,135	7,555	12,090

Table 6. Load Actuator and Support Subsystems Components and Costs

Component Part	Label No.*	Quant. per sub-system	Manufacturer or Vendor (Typical)	Unit Costs, Dollars			
				Subgrade Soil	Vabound Select	Asphalt Stabil-ized	Combined
Air cylinder	3	1	Bellofram Corp., Burlington, MS	130	200	170	500
Actuator Support Plate	-	1	Local Machine Shop	25	25	25	75
Solenoid Valve	11	1	Automatic Switch Co. Florham Park, N.J.	180	180	180	540
Shaft Coupler	4	1	Holokrome Fasteners, Anaheim, CA	60	60	-	60
Muffler		1	Alwitco	10	10	10	30
Total Load Actuator Subsystem Costs				405	475	385	1205

*Numbered on Figure 1.

Table 7. Pneumatic Control Subsystem Components and Costs

Component Part	Label No.*	Percent per sub-system	Manufacturers or Vendor, Typical	Unit Cost, Dollars			
				Subgrade Soil	Unbound Select Granular	Asphalt Stabil-ized	Combined
Air Shutoff valves	7	1	Whitey Co., Oakland, CA	30	30	30	130
Airfilters, 2μ	6	1	Balston, Inc., Lexington, KY	60	60	60	60
Air pressure regulator	10	2	Fairchild, Winston-Salem, N.C.	130	130	65	130
Air surge tanks	5	2	Local purchase	200	200	100	200
Air pressure guages	9	2	3D Instruments, Long Beach, CA	300	300	150	300
Duration timer	8	1	Eagle Branon Instruments Portland, OR	110	110	110	110
Interval Timer	8	1	Eagle, " "	60	60	60	60
Misc. Elec. Parts	-	-	Local electronics Supply	50	50	50	50
120 V. A.C. counter	13	1	" "	20	20	20	20
Total Pneumatic Control Subsystem Costs				960	960	645	960

*Figure 1

Table 8. Test Specimen Mounting Subsystems Components and Costs

Component Part	Label No.*	Percent per Sub-System	Manufacturer or Vendor, Typical	Unit Costs, Dollars			
				Subgrade Soil	Unbound Select Granular	Asphalt Stabil-ized	Combined
Triaxial cell, 4 in.	1	1	Research Engr. San Pablo, CA	1,500	-	-	
Triaxial cell, 6 in.	-	1	" "	-	2,000[1]	-	2,000
Diametral Loading Blocks	-	2	Local machine shop	-	-	25	25
Total Test Specimen Mounting Sybsystems Costs				1,500	2,000	25	2,025

[1] Includes end platens for 4 inch diameter specimens.

*Figure 1

Table 9. Test Specimen Response Subsystems Components and Costs

Component Part	Label No.*	Quantity per sub-system	Manufacturer or Vendor, Typical	Unit Costs, Dollars			
				Subgrade Soil	Unbound Select Granular	Asphalt Stabil-ized	Combined
Load Cell	14	1	Schaevitz Engr. Pennsduken, N.J.	500	500	500	1,000
LVDT's[1]	15	2	" "	400	400	400	400
LVDT clamps	17	2	Local Machine Shop	250	300		300
Diametral yoke assembly	-	1	Local Machine Shop			500	500
Total Test Specimen Response Subsystems Costs				1,150	1,200	1,400	2,200

[1]Linear variable differential transformers.

*Figure 1

Table 10. Miscellaneous Support Apparatus for Resilient Modulus Tests on Subgrade Soils

<u>Sample Preparation Equipment</u>

<u>Impact Compaction</u>

AASHTO T-99 Apparatus
AASHTO T-180 Apparatus

<u>Kneading Compaction</u>

AASHTO T-190 Kneading Compactors
or Harvard Miniature Kneading Compactor
or Soiltest Gyratory Compactor

<u>Static Compaction</u>

Static Compaction Mold and Plunger Assembly of Static Loading Machine

<u>Vibratory Compaction</u>

Split Sample Mold with porous plastic liner
Hand held Vibratory Compaction Hammer

<u>Sample Conditioning Equipment</u>

Back-pressure saturation apparatus
Freezer

<u>Other Miscellaneous Equipment</u>

Apparatus for Trimming Test Specimens
Calipers scales, balances, ovens, membranes, O-rings; vacuum pump, porous stones, moisture cans, water bottles, membrane expander, etc.

The costs shown in Tables 5 through 9 are for test apparatus constructed with all new components. Actual capital outlay costs for all of the alternatives would be slightly less than the amounts shown in the tables because some of the components from the existing ITD device could be incorporated in the new upgraded apparatus. Figure 1 illustrates the components of an assembly suitable for subgrade soils in which the load pulse duration and frequency controller (Number 8 on the figure), the test frame (with modifications) and the Bellofram and solenoid (numbers 3 and 11) from the existing ITD device have been included. Signal conditioning and test specimen response recording equipment is also on hand with the existing ITD device. Thus if it were decided that only subgrade soils are to be tested in the ITD laboratories, the minimum capital outlay devices that would have to be purchased in order to upgrade the ITD device would be a new triaxial cell to accommodate 4 inch diameter by 8 inch long test specimens, ring clamp LVDT supports, and an additional LVDT. The selection of the alternative, whose total estimated costs are listed in Table 11, would make project capital outlay funds available for purchases of additional test specimen preparation and conditioning equipment.

A second alternative recommended for consideration is the single "complete" unit of Table 5. This unit consists of a new test frame and control system for conducting resilient modulus tests <u>on all three</u> general types of pavement construction materials. The large stiff frame and controls could also be used to conduct <u>fatigue</u> tests on asphalt treated materials using the indirect diametral tension mode. Distinguishing features of the new test frame include sufficient horizontal clearance between the vertical air cylinder support rods so that the larger triaxial cells necessary for 4 inch diameter by 8 inch long

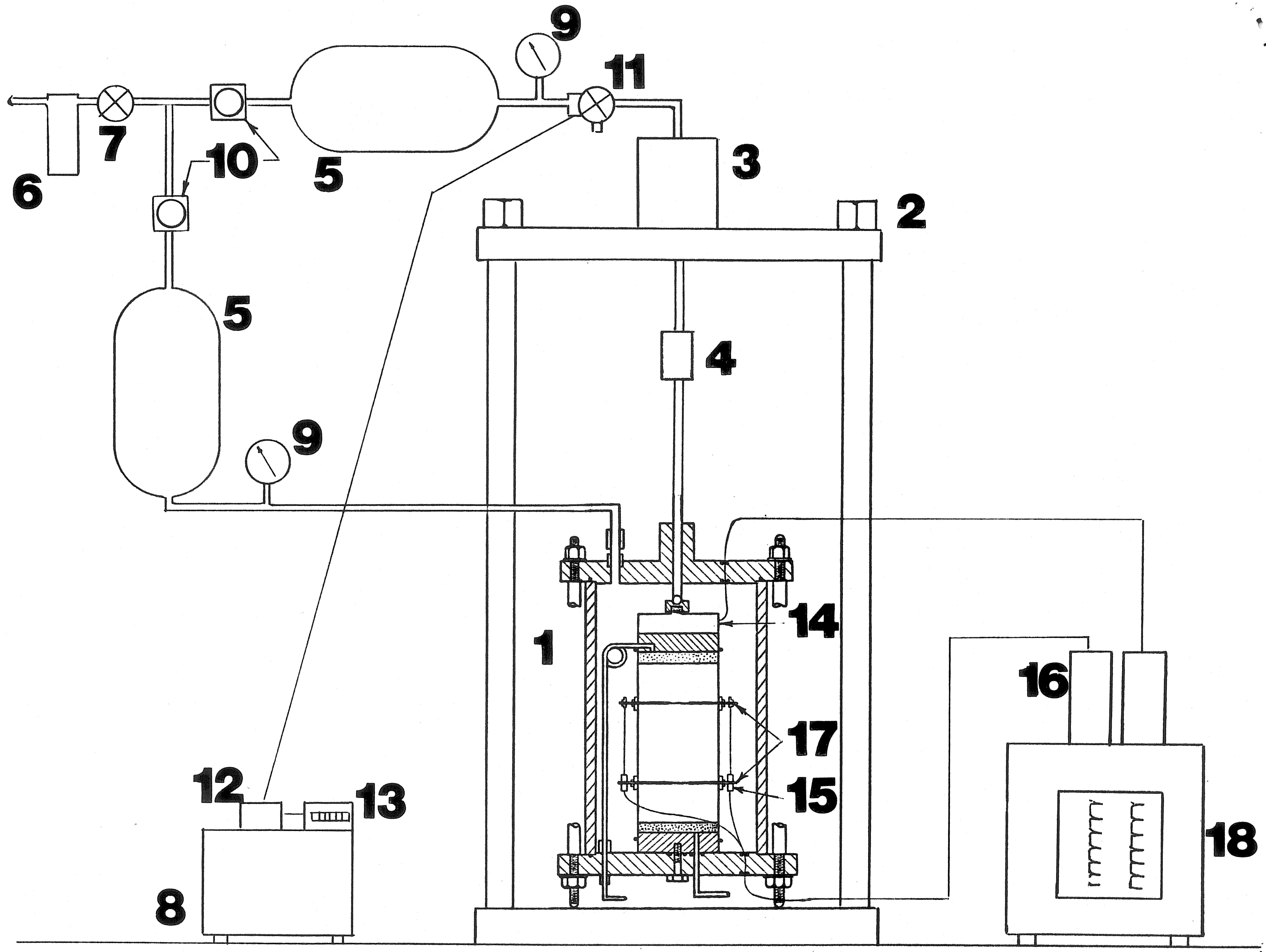


Figure 1. Components of Subgrade Soil Resilient Modulus Test Device

Table 11. Estimated Costs of Upgrading ITD Subgrade Soil Resilient Modulus Test Device.

Label No.*	Item	Quant.	Necessary Action	Cost Dollars
1	Triaxial cell	1	Purchase	1,500
2	Load frame	1	Modify	300
3	Air cylinder (Bellofram)	1	None	-
4	Shaft coupler	1	Purchase	60
5	Air storage tanks	2	Purchase	200
6	Air filters, 2 u	1	Purchase	60
7	Air shutoff valve	1	Purchase	30
8	Frequency and duration controller	1	None	-
9	Air pressure gages	2	Purchase	300
10	Air pressure regulators	2	Purchase	130
11	Solenoid valve	1	None	-
12	Relay and Triac switches	1	None	-
13	Cycle counter	1	None	-
14	Load Cell	1	None	-
15	LVDT's	2	Purchase (1)	250
16	Signal conditioners	2	None	-
17	Two channel analog recorders	1	Purchase	5,000
18	LVDT ring clamps	2	Purchase	500
Total Cost of Upgrading Soil M_R Device				8,330

*Numbered on Figure 1.

test specimens and internal LVDT ring clamps can be accommodated, continuously threaded vertical support rods to permit large-range vertical height adjustments of interchangeable air cylinder support plates, and clamps for centering and fixing the position of the triaxial cells on the load frame table. With the "complete" system, a minimum of two interchangeable air cylinders with support plates and solenoids are required to conduct repeated load triaxial resilient modulus tests on both "soft" materials such as cohesive subgrade soils and "stiff" materials such as dense-graded aggregate or stabilized bases. A third, even larger air cylinder would be necessary to conduct repeated indirect diametral tension fatigue tests on asphalt concrete. As can be seen from the cost data shown in Table 5, the capital outlay funds budgeted in the current project are not sufficient to permit the purchase of the new signal conditioning and recording equipment in addition to the single "complete" testing unit.

Final selection of components for which project capital outlay funds will be used will be made after consultations with ITD.

IV. TEST EQUIPMENT AND PROCEDURE EVALUATION (Task 6)

As indicated in the previous section, the selection of the recommended alternative equipment assemblies was based on information obtained in the literature review, survey questionnaire, discussions with other users of resilient modulus tests, and our own experiences. Similarly, the suggested test procedures for subgrade soils and asphalt treated materials contained in Appendices A and B, respectively, were largely based on applying our own experiences and judgement to procedures described in the literature. Because the equipment and procedures recommended in the study represent what might be termed a "consensus" of experience and because of the considerable expenditures in both time and money required to conduct large numbers of tests using alternate equipment and test procedures, the test program conducted for the project has instead concentrated on defining the sensitivity and reproducibility of test results using the selected equipment components and procedures. In other words, it appeared to be preferable to place the emphasis of the test program in deterimining how accurately and reproducibly resilient modulus can be measured using the procedures and equipment that are generally accepted as a reasonable balance between accuracy and costs of test results.

In order to accomplish the objective stated above and also to provide the University's and Transportation Department's input for the cooperative reproducibility study, 10 complete resilient modulus tests using the suggested standard procedure for subgrade soils given in Appendix A have been completed. Table 12 summarizes the tests conducted thus far. Analysis of the test results within the format of the suggested standard procedure will be included in the final report section describing the cooperative reproducibility study.

V. DEVELOP COMPARATIVE TEST PLAN (Task 7)

The final task of the second phase of the project was to develop a limited cooperative test program to assess the reproducibility of resilient modulus tests conducted by different organizations. This task has been completed and the participating agencies are currently conducting the comparative tests on a "standard" soil supplied by the University of Idaho.

On the recommendation of the Idaho Transportation Department, the soil selected for the cooperative was a silty fine sand from Bovill, Idaho, similar

Table 12. Summary of Subgrade Soil Resilient Modulus Tests.

Test Number	Test Specimen Length Inches	End Condition	Test Device	Dry Density	Water Content	Regression Coefficients[2]		Correlation Coefficient
				pcf	%	K_1	K_2	r
1	8	rough	U of I	117.0	11.8	681	0.347	0.69
2	8	rough	U of I	117.3	11.9	393	0.468	0.68
3	8	rough	U of I	117.0	12.0	899	0.272	0.44
4	8	smooth	U of I	117.0	11.9	1188	0.211	0.34
5	8	Smooth	U of I	117.0	12.1	661	0.474	0.62
6	8	smooth	U of I	117.2	11.9	501	0.597	0.68
7	8	smooth	U of I	116.9	12.0	647	0.469	0.69
8	5	smooth	U of I	117.3	11.8	680	0.548	0.79
9	5	smooth	ITD	117.2	12.0	749	0.132	0.58
10	5	smooth	ITD	117.3	12.0	863	0.119	0.40

[1] All specimens 4 inches in diameter

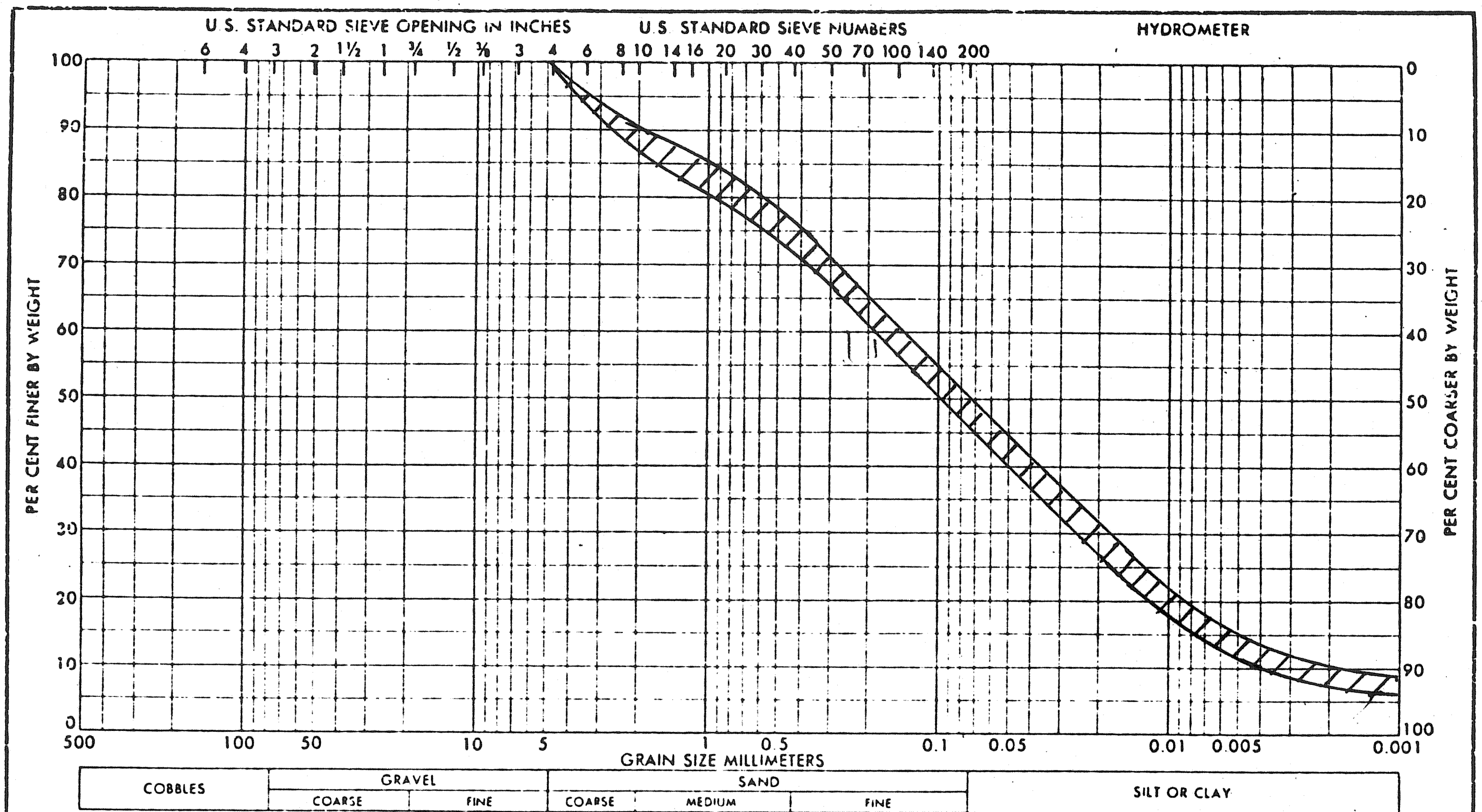
[2] $\ln M_R = K_1 \theta^{K_2}$

to the subgrade soil used in previous studies at the University of Idaho (3, 4). To prepare the soil for distribution to the program's participants, 600 pounds of the soil was removed from a road cut located on State Route 3 approximately 10 miles north of Bovill. The soil was air dried, homogenized by mixing, and divided by successive riffle splits into identical 18 pound samples. The grain size distribution and AASHTO T-99 moisture-density relationship of the resulting soil are shown in Figures 2 and 3, respectively.

The seven organizations listed in Table 13 agreed to participate in the cooperative test program. An 18 pound sample of the air dried standard soil was mailed to each organization along with copies of the suggested standard test procedure, extra data sheets, and the grain size and moisture density relationship for the soil. The participating agencies were asked to test the material at the maximum AASHTO T-99 dry density and optimum water content using the suggested standard procedure insofar as possible. The organizations were requested to return the originals of the completed data sheets for analysis here at the University of Idaho. These data will be combined with the results of the ten test replications already conducted at the University in the analysis of reproducibility and accuracy of resilient modulus tests on subgrade soils (Task 8).

VI. CONCLUSION

The preceeding paragraphs have described briefly the work completed for the project since September of 1980. This work has included the definition of suggested alternative equipment purchases for expansion of the ITD's resilient modulus testing capability. A second meeting between the Principal Investigator staff and the ITD will be scheduled as soon as possible in order

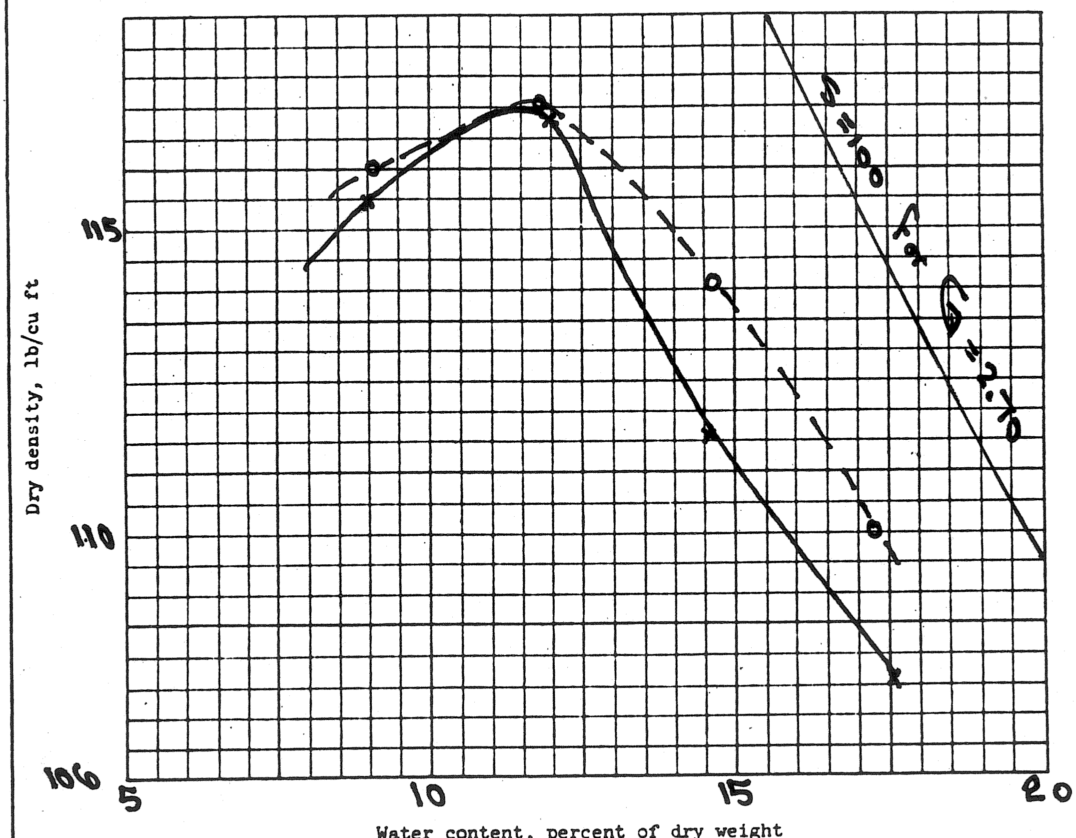


SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1-4	SURFACE	A-4	–	NON PLASTIC		

PROJECT	ITD MODULUS TEST PROCEDURES - STD SOIL
AREA	
BORING NO	
DATE	FEB -81

GRADATION CURVES

Figure 2. Grain Size Distribution of Standard Soil



T-99 compaction test

25 blows per each of 3 layers, with 5.5 lb rammer and

12 inch drop. 4.0 inch diameter mold

Sample No.	Elev or Depth	Classification	G	LL	PL	% > No. 4	% > 3/4 in.
1	SURF-	A-4	2.70	Non Plastic		0	0
1	ACE	A-4	2.70			0	0

Sample No.	1	2		
Natural water content, percent	–	–		
Optimum water content, percent	11.8	11.7		
Max dry density, lb/cu ft	117.1	116.9		

Remarks

2 operators

Project ITD MODULUS TEST PROC

"STANDARD" SOIL

Area

Boring No. — Date Feb 81

COMPACTION TEST REPORT

Figure 3. AASHTO T-99 Moisture-Density Relationship for Standard Soil.

Table 13. Participants in Cooperative Test Program

Agency	Address	Contact Person
Federal Highway Administration	610 E. 5th St. Vancouver, WA 98661	William A. Liddle
Florida Department of Transportation	Office of Materials and Research 2006 NE Waldo Road Gainesville, FL 32602	Charles F. Potts
Georgia Department of Transportation	Office of Materials and Research 15 Kennedy Drive Forrest Park, GA 30050	Thomas Stapler
Idaho Transportation Department	Division of Highways P. O. Box 7129 Boise, ID 83707	Tri Buu
Utah Department of Transportation	Materials and Research Section 757 West 2nd South Salt Lake City, UT 84104	Douglas Anderson
Oregon State University	Transportation Research Institute 207 Apperson Hall Corvallis, OR 97331	R. G. Hicks
University of Idaho	Department of Civil Engineering Moscow, ID 83843	J. H. Hardcastle

to provide the opportunity for discussion and final selection of the alternative which best meets the ITD requirements.

Other work performed during the period covered by the report includes two revisions of the suggested standard test procedure for resilient modulus of subgrade soils and a first draft of a procedure for resilient modulus of asphalt treated materials. A typical Idaho subgrade soil was also selected, prepared, and distributed to 5 pavement materials testing laboratories as part of the cooperative reproducibility testing program of the project. Tests of the soil using the University of Idaho's apparatus as well as the ITD test device have been completed. The results of these tests will be used as input into the interagency reproducibility study. These test results are also being used in analysis aimed at defining the precision of subgrade soil resilient modulus and identifying the sources of error. This work is being done as part of a master of science thesis and will be reported in the project final report along with the reproducibility study.

REFERENCES

1. Hardcastle, J. H. and Lottman, R. P., "Interim Report No. 1 Review and Modification of Resilient Modulus Test Procedures and Apparatus," Report to Idaho Transportation Department, Division of Highways, Department of Civil Engineering, University of Idaho, Moscow, August 1, 1980, 39 pp.

2. Schmidt, R. J., "A Practical Method for Measuring the Resilient Modulus of Asphalt-Treated Mixes," Highway Research Record 404, 1972, pp. 22-32.

3. Hardcastle, J. H., Lottman, R. P., and Buu, T., "Rational Method for Seasonal Load Limits for Flexible Pavement," Proceedings of the Idaho Symposium on Engineering Geology and Soils Engineering, Boise, 1980, pp. 301-322.

4. Stephens, R. L., "The Effect of Water Content Variation and Freeze-Thaw Cycles on the Resilient Modulus of a Silty Highway Subgrade Soil," M.S. Thesis, University of Idaho, Moscow, 1980, 117 pp.

APPENDIX A

Suggested Method of Test

for

Resilient Modulus of Subgrade Soils

Suggested Method of Test for

RESILIENT MODULUS OF SUBGRADE SOILS

AASHTO DESIGNATION:

Second Copy [illegible] 3/34/85

FYI — Need your review & OK as soon as possible. See attached Negatives etc. CBH

1. SCOPE

1.1 These methods cover procedures for preparing and testing untreated soils for determination of dynamic elastic modulus under conditions that represent a reasonable simulation of the physical conditions and stress states of subgrade materials beneath flexible pavements subjected to moving wheel loads.

1.2 The methods described are applicable to undisturbed samples of natural and compacted subgrade materials and to disturbed samples prepared for testing by compaction in the laboratory.

1.3 The values of resilient (dynamic elastic) modulus determined with these procedures can be used in the available linear-elastic and non-linear elastic layered system theories to calculate the physical response of pavement structures.

2. SUMMARY OF THE METHOD

2.1 A repeated axial deviator stress of fixed magnitude, duration, and frequency is applied to an appropriately prepared and conditioned cylindrical test specimen. During and between the dynamic deviator stress applications, the specimen is subjected to a static all-around stress provided by means of a triaxial pressure chamber. The resilient (recoverable) axial strain response of the specimen is measured and used to calculate the dynamic stress-dependent resilient moduli.

3. SIGNIFICANCE AND USE

3.1 The resilient modulus test provides the basic constitutive relationship between stress and deformation of flexible pavement construction materials for use in structural analysis of layered pavement systems.

3.2 The resilient modulus test provides a means of evaluating pavement construction materials, including subgrade soils under a variety of environmental conditions and stress states that realistically simulate the conditions that exist in pavements subjected to moving wheel loads.

4. BASIC DEFINITIONS

4.1 σ_1 is the total axial stress (major principal stress)

4.2 σ_3 is the total radial stress; that is, the applied confining pressure in the triaxial chamber (minor and intermediate principal stresses)

4.3 $\sigma_d = \sigma_1 - \sigma_3$ is the deviator stress, that is, the repeated axial stress for this procedure

4.4 ε_1 is the total axial strain due to σ_d

4.5 ε_r is the resilient (recovered) axial strain

4.6 $M_r = \sigma_d/\varepsilon_r$ is the resilient modulus, i.e., the dynamic stress-strain relationship that can be substituted in analytical procedures involving dynamic traffic loading requiring a modulus of elasticity

4.7 Load duration is the time interval the specimen is subjected to a deviator stress

4.8 Cycle duration is the time interval between successive applications of a deviator stress

4.9 $\gamma_d = \frac{G \gamma_W}{1 + (WG/S)}$ where γ_d = unit weight of dry soil, pounds per cubic foot (kilo-newtons per cubic meter).

G = specific gravity of soil solids, dimensionless

W = water content of soil, (%)

S = degree of saturation, (%)

γ_W = unit weight of water, pounds per cubic foot (kilo-newtons per cubic meter).

NOTE: both W and S must be expressed as either a decimal or a number; e.g., 20% is either .20 or 20, but it is imperative that there is consistency between the two.

5. APPARATUS

5.1 Triaxial Pressure Chamber - The pressure chamber is used to contain the test specimen and the confining fluid during the test. A triaxial chamber suitable for use in resilience testing of soils is shown in Figure 1. The chamber is similar to most standard triaxial cells except that it is somewhat larger to facilitate the internally mounted load and deformation measuring equipment, and has additional outlets for the electrical leads from the measuring devices.

5.1.1 Standard triaxial cells with externally mounted load and deformation measuring equipment (Figure 2) may be used for materials whose maximum resilient modulus is less than 15,000 psi (104,000 kPa).

5.1.2 Air is used as the chamber fluid in both configurations. Water or water/alcohol mixture can also be used.

5.2 Loading Device - The external loading source may be any device capable of providing varying repeated loads in fixed cycles of load and release. These devices range from simple cam and switch control of static weights or air pistons to closed-loop electro-hydraulic systems. A load duration of 0.1 second and cycle duration of from 1 to 3 seconds is required. A sine, haversine, rectangular, or triangular shaped stress pulse form may be used.

5.3 Load and Specimen Response Measuring Equipment

5.3.1 The axial load measuring device is an electronic load cell. Preferably, the load is measured by placing the load cell between the specimen cap and the loading piston as shown in Figure 1. Load cells may also be mounted outside the test chamber provided corrections are made for any dynamic piston friction in the chamber gland.

5.3.2 Test chamber pressures are monitored with conventional pressure gauges, manometers or pressure transducers of suitable sensitivity ranges.

5.3.3 Axial deformation-measuring equipment for use with materials with maximum resilient modulus in excess of 15,000 psi (104,000 kPa) consists of 2 linear variable differential transformers (LVDT's) attached directly to the specimen by a pair of clamps. The clamp and LVDT's are shown in position on a test specimen in Figure 1. Details of the clamps are shown in Figure 3.

5.3.3.1 Axial deformation measurements on materials with maximum resilient modulus less than 15,000 psi (104,000 kPa) may be made with LVDT's clamped to the piston rod outside the test chamber as shown in Figure 2.

5.3.4 It is necessary to maintain suitable signal excitation, conditioning, and recording equipment in addition to the measuring devices for simultaneous recording of axial load and deformations. The LVDT's should be wired so that the average signal from the pair is recorded.

5.3.5 In order to minimize errors in test specimen response measurement and recording, the system is calibrated immediately before and after each test. A device found to be satisfactory for this purpose consists of a high quality load ring supported in an incompressible (steel) jig whose overall dimensions are similar to the test specimen's (Figure 4). To calibrate the system, the device is placed on the base of the triaxial chamber and the load cell and LVDT's are attached. The device is subjected to repeated axial loads of the magnitude and duration used for measuring the resilient response of the test specimen. By holding a card against the face of the load ring dial, the resulting dynamic deflections of the ring can be observed without difficulty. The load ring displacements are compared to the recorded LVDT trace to obtain the deformation calibration.

The load ring's own force-displacement relationship is used to establish the magnitude of load represented by the recorded load cell traces.

5.4 <u>Specimen Preparation Equipment</u> - A variety of test specimen preparation equipment is required to prepare undisturbed samples for testing and to obtain compacted specimens that are representative of field conditions. Use of different materials and different methods of compacting in the field requires the use of varying compaction techniques in the laboratory. Typical equipment required is listed as follows:

5.4.1 Equipment for trimming test specimens from undisturbed samples as described in AASHTO T-234, Strength Parameters of Soils by Triaxial Compression.

5.4.2 Equipment for impact compaction as described in AASHTO T-99, Moisture-Density Relations of Soils Using a 5.5-lb (2.5 kg) Rammer and a 12-in. (305 mm) Drop or AASHTO T-180, Moisture-Density Relations of Soils Using a 10-lb (4.54 kg) Rammer and an 18-in. (457 mm) Drop.

5.4.3 Apparatus for kneading compaction as described in AASHTO T-190, Resistance R-Value and Expansion Pressure of Compacted Soils or other apparatus which utilize kneading methods of compaction.

5.4.4 Apparatus for statically compacting a known weight of moist soil to a predetermined length and diameter fixed by the dimensions of ~~a~~ the mold. A typical mold assembly for the preparation of 2.8-in. (71 mm) diameter by 6-in. (152 mm) high specimen for 3-layer static compaction is shown in Figure 5.

5.4.5 Split mold and hand-held air-operated vibratory compactor as shown in Figure 6.

5.4.6 Static loading machine with an adequate capacity for compacting different materials.

5.5 Miscellaneous Apparatus - This includes calipers, micrometer gauge, steel rule (calibrated to 0.02 in. (0.5 mm)) rubber membranes from 0.01 to 0.025 in. (0.254 to 0.635 mm) in thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones, scales, moisture content cans, and data sheets as required.

6. PREPARATION OF TEST SPECIMENS

6.1 Specimen Size - Specimen length should be not less than two times the diameter. Minimum specimen diameter is the larger of 2.8-in. (71 mm) or six times the largest particle size. Four-inch (102 mm) diameter, 8-in. (203 mm) high specimens can be accommodated in the triaxial cell shown in Figure 1, and this is the minimum size specimen required when the ring clamp LVDT holders shown in Figure 3 are used.

new item

6.2 Undisturbed Specimens - Undisturbed specimens are trimmed and prepared as described in AASHTO T-234, Strength Parameters of Soils by Triaxial Compression.

6.3 Preparation of Soil for Laboratory Compacted Specimens - The following procedure is used to prepare soil samples for laboratory compaction.

6.3.1 If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of drying apparatus such that the temperature does not exceed 60°C (140°F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

6.3.2 Sieve an adequate quantity of the representative pulverized soil over the 3/4-in. (19.0 mm) sieve. Discard the coarse material, if any, retained on the 3/4-in. (19.0 mm) sieve.

6.3.3 Determine the air-dry moisture content w_1 of the soil. The moisture sample shall weigh not less than 200 g for soils with a maximum particle size smaller than 0.187-in. (4.75 mm) and not less than 500 g for soils with maximum particle size greater than 0.187-in. (4.75 mm).

6.3.4 Determine the volume V of the compacted specimen to be prepared. For other than static compaction methods, the height of the compacted specimen must be slightly greater than that required for resilience testing to allow for trimming of the specimen ends. An excess of 0.5-in. (13 mm) is generally adequate for this purpose.

6.3.5 Determine the weight of oven-dry soil solids W_s and water W_c required to obtain the desired dry density γ_d and water content w_c as follows:

$$W_s \text{ (pounds)} = \gamma_d \text{ (pounds per cubic foot)} \times V \text{ (cubic feet)}$$

$$W_s \text{ (grams)} = W_s \text{ (pounds)} \times 454$$

$$W_c \text{ (pounds)} = W_s \text{ (pounds)} \times w_c \left(\frac{\text{Percent}}{100}\right)$$

$$W_c \text{ (grams)} = W_c \text{ (pounds)} \times 454$$

6.3.6 Determine the weight of air-dried soil W_{ad} required to obtain W_s. An additional amount $\underline{W_{as}}$ of at least 500 grams should be allowed to provide material for the determination of water content at the time of compaction.

$$W_{ad} \text{ (grams)} = (W_s + \underline{W_{as}}) \times \left(1 + \frac{w_1}{100}\right)$$

6.3.7 Determine the weight of water W_{aw} required to increase the weight from the existing W_1 to the weight of water W_c corresponding to the desired compaction water content w_c.

$$W_1 \text{ (grams)} = (W_s + \underline{W_{as}}) \times \left(\frac{w_1}{100}\right)$$

$$W_2 = (W_s + W_{as}) \times \left(\frac{\cancel{w}\ w_c}{100}\right)$$

$$W_{aw} \text{ (grams)} = W_2 - W_1$$

6.3.8 Determine the wet weight of soil W_t to be compacted.

$$W_t \text{ (grams)} = W_s \times \left(1 + \frac{w_c}{100}\right)$$

6.3.9 Place the mass of soil W_{ad} determined in 6.3.6 into a mixing pan.

6.3.10 Add the water W_{aw} to the soil in small amounts and mix thoroughly after each addition.

6.3.11 Place the mixture in a plastic bag. Seal the bag and store it in an atmosphere of at least 75 percent relative humidity for 24 hours. Ensure a complete seal by using 2 or more bags.

6.3.12 After mixing and storage, weigh the wet soil and container to the nearest gram and record this value on the appropriate forms as shown in Figure 7 and 8.

6.4 Compacting Specimens of Cohesive Soils - The resilient behavior of compacted cohesive soils containing substantial amounts of clay is dependent on the structure imparted to the soil particles by the compaction process. Cohesive soils containing substantial amounts of clay are defined for this procedure as soils classified A-2-6, A-2-7, A-6 and A-7 using the criteria of AASHTO M-145, The Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes.

6.4.1 Selection of Compaction Method - The method of compaction and the compaction (molding) water content w_c of cohesive soils depends on the field condition to be simulated by the laboratory specimen.

6.4.1.1 Specimens representing cohesive subgrades compacted at water contents corresponding to less than 80 percent saturation which remain in the as-constructed condition can be compacted to the field dry density and water content by any standard gyratory, kneading, or static procedures.

6.4.1.2 Test specimens representing a subgrade that was originally compacted at a water content less than that corresponding to the 80 percent saturation value, but which has subsequently experienced an increase in in-service water content are compacted at the in-service water content using the static method described in 6.4.4.

6.4.1.3 Kneading is used for test specimens representing the field compaction and in-service conditions of 6.4.1.2 only if the specimens are compacted at the initial field (as-constructed) water content and then subjected to post-compaction changes in water content. Controlled post-compaction changes in water content are limited in the laboratory to the back pressure saturation techniques described in 6.4.5.

6.4.1.4 Test specimens representing cohesive subgrades compacted in the field at water contents greater than the 80 percent saturation value are compacted in the laboratory using kneading compaction. These test specimens may also be subjected to post-compaction water content increases if the field material to be represented has experienced post-compaction water content increases.

6.4.1.5 Table I summarizes the above discussion of compaction method selection.

6.4.2 Moisture Density Relationships - When the range of compaction conditions and the range of in-service conditions are known, select the required laboratory compaction method from the alternatives listed. If the in-service conditions are not well defined, prepare and test specimens over a range of dry densities and water contents. Four steps are followed to select the densities, water contents, and compaction methods used to prepare specimens representative of the range of resilient behavior:

6.4.2.1 Establish the moisture-density relationship for the soil according to the procedure of AASHTO T-99, Moisture-Density Relations of Soils Using a 5.5 lb. (2.5 kg) Rammer and a 12-in. (30.5 cm) Drop.

6.4.2.2 Determine the specific gravity of the soil according to the procedure of AASHTO T-100, Specific Gravity of Soils.

6.4.2.3 Use the data obtained in 6.4.2.1 and 6.4.2.2 to determine 100 and 80 percent of saturation at various densities. Place this information on the graph of the moisture-density relationship determined in 6.4.2.1; that is, draw a 100 percent and an 80 percent saturation line.

6.4.2.4 Select the densities, water contents, and compaction methods to be used to prepare test specimens.

6.4.3 Compaction by Kneading Methods - Standard molds associated with kneading compaction methods such as AASHTO T-190 or the Harvard miniature method may not be of the correct dimensions for direct use in resilience testing. However, molds of the correct dimensions can be obtained, and the methods referred to above can be adapted to the new mold sizes. This generally will require trial-and-error adjustments in the number of compacted layers or the number of tamps per layer (or both) to produce specimens of the required densities. Large size compacted specimens also can be prepared and the correct size test specimen trimmed from the larger compacted specimen. Eight steps are required for the kneading compaction procedure.

6.4.3.1 Establish the number of layers N to be used to compact the soil. Determine the wet weight of soil required per layer, W_L. Layer thickness should not exceed 2 inches.

$$W_L \text{ (grams)} = \frac{W_t}{N}$$

6.4.3.2 Place the mass of soil determined in Step 1 in the mold. Compact according to the procedure established for the mold dimensions and compactor used. Scarify the surface for the remaining layers.

6.4.3.3 Repeat Step 2 for the remaining layers.

6.4.3.4 After the specimen has been completed, determine (verify) the compaction water content, w_c of the remaining soil. The moisture sample shall weigh not less than 200 g for soils with a maximum particle size smaller than 0.187-in. (4.75 mm) and not less than 500 g for soils with maximum particle size greater than 0.187-in. (4.75 mm). Record this value on a form for cohesive soils as shown in Figure 7.

6.4.3.5 Carefully remove the specimen from the mold. If the compacted specimen is not of the desired dimensions, trim the test specimen in accordance with the procedures described in AASHTO T-234, Strength Parameters of Soils by Triaxial Compression. If the compaction mold has the same dimensions as the desired test specimen, plane end surfaces can be obtained by applying a small static load to the specimen before it is carefully removed from the mold.

6.4.3.6 Weigh the specimen to the nearest gram. Determine the average height and diameter to the nearest 0.02-in (0.5 mm). Record these values on a form for cohesive soils as shown in Figure 7.

6.4.3.7 Using a vacuum membrane expander, place the thin leak-proof membrane over the specimen. Place O-rings or other pressure seals around the membrane to provide a positive seal to top and bottom solid end platens like those used with the triaxial chamber.

6.4.3.8 Wrap the membrane-enclosed sample in a plastic bag, seal, and place it in an atmosphere of at least 75 percent relative humidity for a period of not less than 24 hours to insure a uniform moisture distribution. If no post-compaction conditioning such as freeze-thaw cycling or back pressure saturation is to be used, the specimen is now ready for transfer to the triaxial chamber for resilience testing.

6.4.4 Compaction by Static Loading - In the absence of standard methods for static compaction, the method described in this procedure is used. The process is one of compacting a known weight of wet soil to a volume that is fixed by the dimensions of the mold assembly. A typical mold assembly for the preparation of a specimen with a 2.8-in. (71 mm) diameter and a 6-in. (152 mm) height using 3 layers is shown in Figure 5. Other suitable equipment and number of layers necessary to produce specimens of larger dimensions can be developed. Sixteen steps are required for static compaction.

6.4.4.1 Establish the number of layers N to be used to compact the soil. The thickness of individual layers should be limited to 2 inches. Determine the weight of wet soil per layer.

$$W_L \text{ (grams)} = \frac{W_t}{N}$$

6.4.4.2 Place one of the loading rams into the sample mold.

6.4.4.3 Place the mass of soil W_L determined in Step 1 into the sample mold. Use a spatula to draw the soil away from the edge of the mold and form a slight mound in the center.

6.4.4.4 Insert the second loading ram and place the assembly in the static loading machine. Apply a small load. Adjust the mold so that it rests equidistant from the caps of the load rams. Soil pressure developed by the initial loading will serve to hold the mold in place. By having both loading rams reach the zero volume change positions simultaneously, more uniform layer densities are obtained.

6.4.4.5 Slowly increase the load until the loading ram caps rest firmly against the mold. Hold the load at or near the maximum load for not less than one minute. The rate of loading and load duration depend on the amount of soil rebound. The slower the rate of loading and the longer the load is held, the less the rebound.

6.4.4.6 Decrease the load to zero and remove the assembly from the loading machine.

6.4.4.7 Remove a loading ram. Scarify the surface of the compacted layer, put the correct weight of soil W_L for a second layer in place, and adjust the soil as in Step 3. Add a spacer ring and insert the loading ram.

6.4.4.8 Invert the assembly and repeat Step 7.

6.4.4.9 Place the assembly in the loading machine. Load slowly while holding the load at or near maximum when the spacer disk firmly contacts the mold.

6.4.4.10 Repeat Steps 6, 7, 8 and 9 as required.

6.4.4.11 After the specimen has been completed determine (verify) the compaction water content w_c of the remaining soil. The moisture sample shall weigh not less than 200 g for soils with maximum particle size smaller than 0.187-in. (4.75 mm) and not less than 500 g for soils with maximum particle size greater than 0.187-in. (4.75 mm). Record this value on a form for cohesive soils as shown in Figure 7.

6.4.4.12 Place the extruder ram into the sample mold and force the specimen out of the sample mold into the extrusion mold.

6.4.4.13 Use the extrusion mold to carefully slide the compacted specimen onto a glass plate.

6.4.4.14 Determine the weight of the compacted specimen to the nearest gram. Measure the height and diameter to the nearest 0.02-in. (0.5 mm). Record these values on a form for cohesive soils as shown in Figure 7.

6.4.4.15 Using a vacuum membrane expander, place the thin leak-proof membrane over the specimen. Place O-rings or other pressure seals around the membrane to provide a positive seal to solid top and bottom end platens similar to those to be used with triaxial chamber.

6.4.4.16 Age the specimen as described in 6.4.3.8. If no post-compaction conditioning such as post-compaction back pressure saturation or freeze-thaw cycling is to be used, the specimen is now ready for transfer to the trixial chamber for resilience testing.

6.4.5 Post-Compaction Back-Pressure Saturation of Undisturbed or Compacted Cohesive Soil Specimens - If a specimen of undisturbed soil or cohesive soil compacted by the methods of 6.4.3 or 6.4.4 is to be saturated before testing, the following 22 steps are required.

6.4.5.1 Remove the test specimen from solid end platens by first removing the rubber O-rings and then carefully folding or rolling the membrane back from the ends of the specimen a distance of approximately one-quarter inch (6.4 mm).

6.4.5.2 Place a saturated porous stone on top of the pedestal or bottom end platen of the triaxial chamber. Saturate the bottom drainage line of the triaxial chamber and the pore pressure measuring device prior to beginning this process by forcing de-aired water through it. If a removable type bottom platen is used, tighten it firmly to the triaxial chamber to obtain an airtight seal.

6.4.5.3 With the bottom drainage valve closed, place the test specimen on the saturated porous stone, carefully fold down the membrane, and seal the membrane to the pedestal or bottom end platen with an O-ring or other pressure seal.

6.4.5.4 Place the top porous stone and top end platen (with vacuum saturation inlet) on top of specimen, fold up the membrane, and seal it to the top end platen.

6.4.5.5 With the drainage line to the bottom of the specimen closed, connect the vacuum inlet at the top of the specimen to a vacuum source through the medium of a bubble chamber and apply a vacuum of 5 psi (35 kPa). If bubbles are absent, an airtight seal has been obtained for the system. If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the end platens.

6.4.5.6 When leakage has been eliminated, disconnect the vacuum supply. If specimen response is to be measured using internal clamp-mounted LVDT's, Steps 7, 8, and 9 are required. If externally mounted LVDT's are to be used, the method continues with Step 10.

6.4.5.7 Open the lower LVDT clamp and carefully clamp it at approximately the lower quarter point of the specimen.

6.4.5.8 Repeat Step 7 for the upper clamp, placing it at the upper quarter point. Ensure that both clamps lie in horizontal planes.

6.4.5.9 Connect the LVDT's to the recording unit and balance the recording bridges. This will require recorder adjustments and adjustment of the LVDT stems. When a recording bridge balance has been obtained, determine to the nearest 0.02-in. (0.5 mm) the vertical spacing between the LVDT clamps and record this value on a form for cohesive soils as shown in Figure 7.

6.4.5.10 Set the load cell in place on the sample cap if the internal load cell configuration of Figure 1 is used.

6.4.5.11 Place the chamber cyclinder and cover plate. Insert the loading piston and obtain a firm connection with the load cell.

6.4.5.12 Tighten the chamber tie rods firmly.

6.4.5.13 Slide the assembled apparatus into position under the axial loading device. Bring the loading device down and couple it to the triaxial chamber piston.

6.4.5.14 Connect the chamber pressure supply line and apply confining pressure of 5 psi (35 kPa).

6.4.5.15 Connect the bottom specimen drainage line to a reservoir of de-aired distilled water for which a back pressure can be controlled and monitored.

6.4.5.16 Reconnect the specimen top drainage line to the vacuum source through the bubble chamber. Apply a vacuum of 3 psi (21 kPa) to the top of the specimen.

6.4.5.17 Open the bottom drainage valve and allow water to be drawn up slowly through the specimen. When water appears to flow out of the specimen in the top drainage line, disconnect the vacuum source from the specimen.

6.4.5.18 Connect the top drainage line to a second reservoir of de-aired distilled water. Maintain the back pressure in this reservoir 5 psi (35 kPa) lower than the pressure in the reservoir connected to the bottom of the specimen.

6.4.5.19 Raise the chamber pressure and back pressure slowly in increments of 5 psi (35 kPa) to 75 psi (518 kPa) and 70 psi (483 kPa) respectively, being careful to maintain the chamber pressure approximately 5 psi (35 kPa) greater than the back pressure in the bottom drainage reservoir in order to prevent flow between the specimen and the membrane.

6.4.5.20 Continue to flush water through the system by maintaining the 5 psi (35 kPa) difference in back pressures applied to the top and bottom drainage line reservoirs until all air has been eliminated.

6.4.5.21 When all air has been eliminated from the test specimen, an increase in chamber pressure (with valves to the top and bottom back pressure reservoirs closed) will result in an approximately equal increase in pore pressure. When this condition is achieved (it may take several days) reduce the back pressures to zero and the chamber pressure to 5 psi (35 kPa), again being careful to maintain the chamber pressure 5 psi greater than the back pressure.

6.4.5.22 After both back pressures have been reduced to zero, disconnect both the top and bottom specimen drainage lines and open them to atmospheric pressure (outside the triaxial chamber). The specimen is now ready for resilience testing.

6.5 Compacting Specimens of Granular Soils - Granular soils that exhibit sufficient cohesion (apparent) to permit handling (removal from the mold, transporting, and sealing in the rubber membrane) can be compacted by the methods described in 6.4.3 and 6.4.4. However, it is generally not necessary to consider soil structure effects. The exceptions are some plastic silts that may also exhibit resilient properties that are dependent on compaction conditions. Granular materials that cannot be handled are compacted as described in 6.5.2.

6.5.1 Moisture Density Relationships - When the range of field densities and moisture conditions to be represented by the test specimen is known, laboratory test specimens can be compacted directly to the in-service water content using the methods of 6.4.3, 6.4.4, or 6.5.2. If the service conditions are not well defined, prepare and test specimens over a range of dry densities and water contents. Establish the moisture-density relationship of the soil according to the procedure of AASHTO T-99, Moisture-Density Relations of Soils Using a 5.5-lb. (2.5 kg) Rammer and a 12-in. (30.5 cm) Drop.

6.5.2 Compacting Granular Soil Using a Split Mold and Vibrator - Cohesionless granular materials are compacted readily by use of a split mold mounted on the base of the triaxial cell as shown in Figure 6. Compaction forces are generated by a vibrator, such as a small hand-operated air hammer. Twenty-six steps are required to compact the specimen.

6.5.2.1 Tighten the sample base into place on the triaxial cell base. It is essential that an air tight seal be developed.

6.5.2.2 Place the two porous stones plus the sample cap on the sample base. (Two stones are required for saturated specimens, but generally only the lower stone would be used for tests of unsaturated specimens). Determine the height of base, cap, and stones to the nearest 0.02-in. (0.5 mm), and record this value on a form for granular soils as shown in Figure 8.

6.5.2.3 Remove the sample cap and upper porous stone if used. Measure the thickness of the rubber membrane with a micrometer gage. Record this value on a form for granular soils as shown in Figure 8.

6.5.2.4 Place the rubber membrane over the sample base and lower porous stone. Fix the membrane in place with an O-ring seal.

6.5.2.5 Place the split-mold sample former around the sample base and draw the rubber membrane up through the mold. Tighten the split mold firmly into place. Exercise care to avoid pinching the membrane.

6.5.2.6 Stretch the membrane tightly over the rim of the mold. Apply a vacuum to the mold to remove all membrane wrinkles. The use of the porous plastic forming jacket liner as shown in Figure 6 helps to insure that the membrane fits smoothly around the inside perimeter of the mold. The vacuum is maintained throughout the compaction procedure.

6.5.2.7 Use calipers to determine to the nearest 0.02-in. (0.5 mm) the inside diameter of the membrane-lined mold. Determine to the nearest 0.02-in. (0.5 mm) the distance from the top of the porous stone to the rim of the mold.

6.5.2.8 Determine the volume V of specimen to be prepared. The diameter of the specimen is the diameter in Step 7 and height is a value less than that determined in Step 7 but at least 2 times the diameter.

6.5.2.9 Determine the weight of material that must be compacted into the volume V determined in Step 8 to obtain the desired density and water content as described in 6.3.4 through 6.3.8.

6.5.2.10 Determine the number of layers N to be used for compaction. Normally, layer depths will be 1 to 1.5-in. (25.4 to 38.1 mm). Determine the weight of wet soil required for each layer W_L as in 6.4.3.1.

6.5.2.11 Place the total required mass of soil W_{ad} into a mixing pan. Add the required amount of water W_{aw} and mix thoroughly.

6.5.2.12 Determine the weight of wet soil plus mixing pan and record on a form for granular soils as shown in Figure 8.

6.5.2.13 Place the amount of wet soil W_L required for 1 layer into the mold. Exercise care to avoid spillage. Use a spatula to draw the material away from the edge of the mold and form a small mound at the center of the mold.

6.5.2.14 Insert the vibrator head and vibrate the soil until the distance from the surface of the compacted layer to the rim of the mold is equal to the distance measured in Step 7 minus the thickness of the lift selected in Step 10. This may require removal and reinsertion of the vibrator head several times until experience is obtained in gauging the required vibration time.

6.5.2.15 Repeat Steps 13 and 14 for each new lift. The measured distance from the surface of the compacted layer to the rim of the mold is successively reduced by the thickness of each new lift from Step 10. The final surface should be a smooth, horizontal plane.

6.5.2.16 When compaction is completed, observe the weight of the mixing pan plus excess soil and record it on a form for granular soils as shown in Figure 8. The weight determined in Step 12 less the weight observed is the weight of wet soil incorporated in the specimens. Determine (verify) the compaction water content w_c of the soil remaining in the pan. The moisture sample shall weigh not less than 200 g for soils with a maximum particle size smaller than 0.187-in.

(4.75 mm). Record this value on a form for granular soil as shown in Figure 8.

6.5.2.17 Place the porous stone and top sample cap on the surface of the specimen. Roll the rubber membrane off the rim of the mold and over the sample cap. If the sample cap projects above the rim of the mold, the membrane should be sealed tightly against the cap with an O-ring seal. If it does not, the seal can be applied later.

6.5.2.18 Connect the vacuum-saturation inlet to a vacuum source and apply 5 psi (35 kPa) of vacuum through the medium of a bubble chamber. The vacuum serves to detect leakage and to impart a stress induced rigidity to the material to prevent collapse when the mold is removed.

6.5.2.19 Carefully remove the sample mold. Seal the membrane to the sample cap if this has not been done. Determine to the nearest 0.02-in. (0.5 mm) the height of specimen plus cap and base and the diameter of the specimen plus membrane. Record these values on a form for granular soils as shown in Figure 8.

6.5.2.20 Observe the presence or absence of air bubbles in the bubble chamber. If bubbles are absent, an airtight seal has been obtained. If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the cap and base. The existence of an airtight seal ensures that the membrane will remain firmly in contact with the specimen. This is essential for use of the clamp mounted internal LVDT's. Leakage through holes in the membrane can frequently be eliminated by coating the surface of the membrane with liquid rubber latex or by using a second membrane.

6.5.2.21 When leakage has been eliminated, open the lower LVDT clamp and place it carefully over the specimen at approximately the lower quarter point of the specimen.

6.5.2.22 Repeat Step 21 for the upper clamp and place it at the upper quarter point. Ensure that both clamps lie in horizontal planes.

6.5.2.23 Connect the LVDT's to the recording unit and balance the recording bridges. This will require recorder adjustments and adjustment of the LVDT stems. When a recording bridge balance has been obtained, determine to the nearest 0.02-in. (0.5 mm) the vertical spacing between the LVDT clamps and the record this value on a form for granular soils as shown in Figure 8.

6.5.2.24 Place the load cell on the specimen end platen, assemble the remainder of the cell, and tighten the tie rods firmly. Slide the assembled apparatus into position under the axial loading device, and couple the actuator and triaxial cell pistons.

6.5.2.25 Connect the chamber pressure supply line and apply a pressure of 5 psi (35 kPa).

6.5.2.26 Remove the vacuum supply from the vacuum saturation inlet and close this line. If the specimen is to be tested at the as-compacted water content, it is now ready for resilience testing. If the specimen is to be subjected to post-compaction back-pressure saturation, the steps listed in 6.5.3 are completed.

6.5.3 Post-Compaction Back-Pressure Saturation of Granular Soils - Test specimens of granular soil to be saturated by back pressure flushing are prepared by the method described in 6.5.2. After completing the steps of 6.5.2, the following additional steps are necessary to saturate the soil.

6.5.3.1 Connect the vacuum supply to the vacuum inlet (at the top of the specimen) and connect the bottom drainage line to a source of de-aired distilled water.

6.5.3.2 Apply a vacuum of 2 to 3 psi (14 to 21 kPa), open the bottom water drainage valve, and allow water to be drawn slowly upward through the specimen.

6.5.3.3 Continue to flush water through the system to remove all entrapped air. To evaluate the presence or absence of air the pore water pressure response to a chamber pressure increase is observed as described for cohesive soils in 6.4.5.21.

6.5.3.4 When all air has been eliminated, set the chamber pressure at 10 psi (69 kPa), apply a 5 psi (35 kPa) back pressure to the water supply while closing the vacuum inlet valve. The effective confining pressure (5 psi (35 kPa)) on the specimen is now equal to the chamber pressure (10 psi (69 kPa)) minus the back pressure (5 psi (35 kPa)). The saturated specimen is now ready for resilience testing.

7. PROCEDURE

7.1 Resilience Tests on Cohesive Soils - The procedures described in this section are used for undisturbed and laboratory compacted specimens of cohesive subgrade soils as defined in 6.4.

7.1.1 Assembly of Triaxial Chamber - Resilience testing of specimens previously subjected to the back-pressure saturation procedures of section 6.4.5 begins with Step 7.1.2. Specimens trimmed from undisturbed samples and laboratory compacted specimens which have not been subjected to the post-compaction back-pressure saturation techniques are placed in the triaxial chamber and loading apparatus in the following steps.

7.1.1.1 Place the triaxial chamber base assembly on the platform of the loading machine. If the chamber has a removable bottom platen (sample base) tighten it firmly to obtain an airtight seal.

7.1.1.2 Remove the solid end platens from the previously membrane-enclosed test specimen by first removing the rubber O-rings and then carefully folding or rolling the membrane back from the ends of the specimen a distance of approximately one-quarter inch (6.4 mm).

7.1.1.3 Place a porous stone on the top of the pedestal or bottom end platen of the triaxial chamber.

7.1.1.4 Carefully place the specimen on the porous stone, fold down the membrane, and seal the membrane to the pedestal or end platen with an O-ring or other pressure seal.

7.1.1.5 Place the top platen (sample cap) and load-cell on the specimen, fold up the membrane, and seal it to the top platen.

7.1.1.6 Close the valve on the vacuum saturation line to the top platen (this line is not required for resilience testing of specimens not subjected to post-compaction saturation; closing the valve will prevent loss of air from the chamber during testing).

7.1.1.7 Connect the specimen's bottom drainage line to a vacuum source through the medium of a bubble chamber. Apply a vacuum of 3 psi (21 kPa). If bubbles are present, check for leakage as described in 6.4.5.5.

7.1.1.8 When leakage has been eliminated disconnect the vacuum supply. Install the LVDT's, assemble the triaxial cell, and position it under the axial loading device as described in 6.4.5.7 through 6.4.5.14.

7.1.2 <u>Conduct of Resilience Test</u> - Twelve steps are necessary to conduct the resilient modulus test on cohesive soils which have been installed in the triaxial chamber and placed in the loading apparatus as described in either 6.4.5 or 7.1.1.

7.1.2.1 Open all drainage valves leading into the specimen.

7.1.2.2 If it is not already connected, connect the chamber pressure supply line and apply a confining pressure (chamber pressure) of 6 psi (41 kPa) to the test specimen.

7.1.2.3 Rebalance the recording bridges for the LVDT's and load-cell.

7.1.2.4 Begin the test by applying 200 repetitions of a deviator stress of 1 psi (6.9 kPa) and then 200 repetitions each of 2, 4, 8, and 10 psi (14, 28, 55, and 69 kPa). The foregoing stress sequence constitutes sample conditioning, that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This load conditioning also aids in minimizing the effects of initially imperfect contact between the end platens and the test specimen.

7.1.2.5 Decrease the deviator stress to 1 psi (6.9 kPa). Apply 200 repetitions of deviator stress and record the recovered deformations at the 200th repetition on a form for cohesive soils as shown in Figure 7.

7.1.2.6 Decrease the confining stress (chamber pressure) to 3 psi (21 kPa). Repeat Step 5.

7.1.2.7 Decrease the confining stress (chamber pressure) to zero. Repeat Step 5.

7.1.2.8 Increase the confining stress (chamber pressure) to 6 psi (41 kPa) and the deviator stress to 2 psi (14 kPa), apply 200 repetitions of load and record the vertical recovered deformations at the 200th repetition.

7.1.2.9 With the deviator stress at 2 psi (14 kPa), apply 200 deviator stress repetitions and record vertical recovered deformations at successive confining stresses (chamber pressures) of 3 psi (21 kPa) and zero.

7.1.2.10 Continue recording the vertical recovered deformations after 200 repetitions of the constant deviator stress-decreasing confining stress (chamber pressure) sequence for deviator stress values of 4, 8, and 10 psi (28, 55, and 69 kPa).

7.1.2.11 At the completion of the loading (with chamber pressure at zero) disassemble the triaxial cell and remove the LVDT clamps.

7.1.2.12 Use the entire specimen for determining the water content. Record this value on the form for cohesive soils as shown in Figure 7.

7.2 <u>Resilience Testing of Granular Soils</u> - The procedures listed in this section are used for both saturated and unsaturated specimens of cohesionless soils. For soils saturated after compaction using the steps of 6.5.3, the confining stresses called for in the conditioning phase are effective confining stresses; that is, the confining stress is equal to the chamber pressure less the back pressure.

7.2.1 After the test specimen has been prepared and placed in the loading device as described in 6.5.2 or 6.5.3, the following steps are necessary to conduct the resilient modulus testing:

7.2.1.1 If not already done, adjust the position of the axial loading device or triaxial chamber base support as necessary to couple the load-generation device piston and the triaxial chamber piston. The triaxial chamber piston should bear firmly on the load cell.

7.2.1.2 Rebalance the recording bridges for the LVDT's and loadcell.

7.2.1.3 Set the confining stress to 5 psi (35 kPa) and apply 200 repetitions of an axial deviator stress of 5 psi (35 kPa). For saturated specimens the drainage valve from the base of the specimen to the back-pressure reservoir is open throughout the resilience testing.

7.2.1.4 Set the axial load generator to apply a deviator stress of 10 psi (69 kPa). Activate the load generator and apply 200 repetitions of this load.

7.2.1.5 Set the confining stress to 10 psi (69 kPa) and apply 200 repetitions of an axial deviator stress of 10 psi (69 kPa).

7.2.1.6 Apply 200 repetitions of an axial deviator stress of 15 psi (104 kPa).

7.2.1.7 Set the confining stress to 15 psi (104 kPa) and apply 200 repetitions of an axial deviator stress of 15 psi (104 kPa).

7.2.1.8 Apply 200 repetitions of an axial deviator stress of 20 psi (138 kPa).

7.2.1.9 If the specimen is one which has been saturated by the back-pressure saturation procedures of 6.5.3 reduce the back-pressure to zero.

7.2.1.10 Begin the recorded resilient modulus test by using a confining pressure of 20 psi (138 kPa) and a deviator stress of 1 psi (6.9 kPa). Record the vertical recovered deformations on a form for granular soils like that shown in Figure 8 after 200 repetitions have been applied.

7.2.1.11 Increase the deviator stress to 2 psi (14 kPa) and record the vertical recovered deformations after 200 repetitions. Continue to record vertical recovered deformations after 200 repetitions for deviator stress levels of 5, 10, and 20 psi (35, 69 and 138 kPa)

7.2.1.12 Reduce the confining pressure to 15 psi (104 kPa) and record vertical recovered deformations after application of 200 repetitions of each of the following deviator stress levels: 1, 2, 5, 10 and 20 psi (6.9, 14, 35, 69 and 138 kPa).

7.2.1.13 Reduce the confining pressure to 10 psi (69 kPa) and record vertical recovered deformations after application of 200 repetitions of each of the following deviator stress levels: 1, 2, 5, 10, and 15 psi (6.9, 14, 35, 69, and 104 kPa).

7.2.1.14 Reduce the confining pressure to 5 psi (35 kPa) and record vertical recovered deformations after application of 200 repetitions of each of the following deviator stress levels: 1, 2, 5, 10, and 15 psi (6.9, 14, 35, 69, and 104 kPa).

7.2.1.15 Reduce the confining pressure to 1 psi (6.9 kPa) and record vertical recovered deformations after application of 200 repetitions of each of the following deviator stress levels: 1, 2, 5, 7.5 and 10 psi (6.9, 14, 35, 52, and 69 kPa). Stop the loading after 200 repetitions of the last deviator stress level or when the specimen fails.

7.2.1.16 Reduce the chamber pressure to 0, dismantle the cell, and remove the LVDT clamps.

7.2.1.17 Use the entire test specimen to determine the water content. Record this value on the form for granular soils as shown in Figure 8.

8. CALCULATIONS

8.1 Calculations are performed by using the tabular arrangement from a form as shown in Figure 7 and 8.

9. REPORT

9.1 Cohesive Soils - The report for resilient modulus tests on cohesive material shall include the following:

9.1.1 Data sheets with calculations in tabular form as shown in Figure 7 for each specimen tested.

9.1.2 Plots showing variation in resilient modulus with deviator stress and confining stress of the form shown in Figure 9 for each specimen tested.

9.1.3 Plot of moisture-density relation for the soil tested showing the 100 and 80 percent saturation lines and the points (moisture-density coordinate) of the specimens tested.

9.1.4 Remarks - note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained.

9.2 Granular Soils - The report for resilient modulus tests on granular materials shall include the following:

9.2.1 Data sheets with calculations in tabular form as shown in Figure 8 for each specimen tested.

9.2.2 Plots showing variations in resilient modulus with deviator stress and confining stress of the form shown in Figure 9 for each specimen tested.

9.2.3 Log-log plot of resilient modulus versus the sum of the principal stresses of the form shown in Figure 10 for each specimen tested. Values of the regression constants K_1 and K_2 shall be stated on each plot.

9.2.4 Plot of moisture-density relation for the soil tested showing the 100 and 80 percent saturation lines and the points (moisture-density coordinates) of the specimens tested.

9.2.5 Remarks - note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained.

TABLE I SELECTION OF COMPACTION METHOD

GYRATORY	KNEADING	STATIC
Subgrades compacted at a water content less than 80% saturation and remain in that condition		
		Subgrades compacted at a water content less than 80% saturation and water. content subsequently increases
	Sample oompacted at initial field water content & subjected to post construction change in water content	
	Subgrades compacted at a water content greader than 80% saturation	

TRIAXIAL CHAMBER WITH INTERNAL LVDT'S AND LOAD CELL

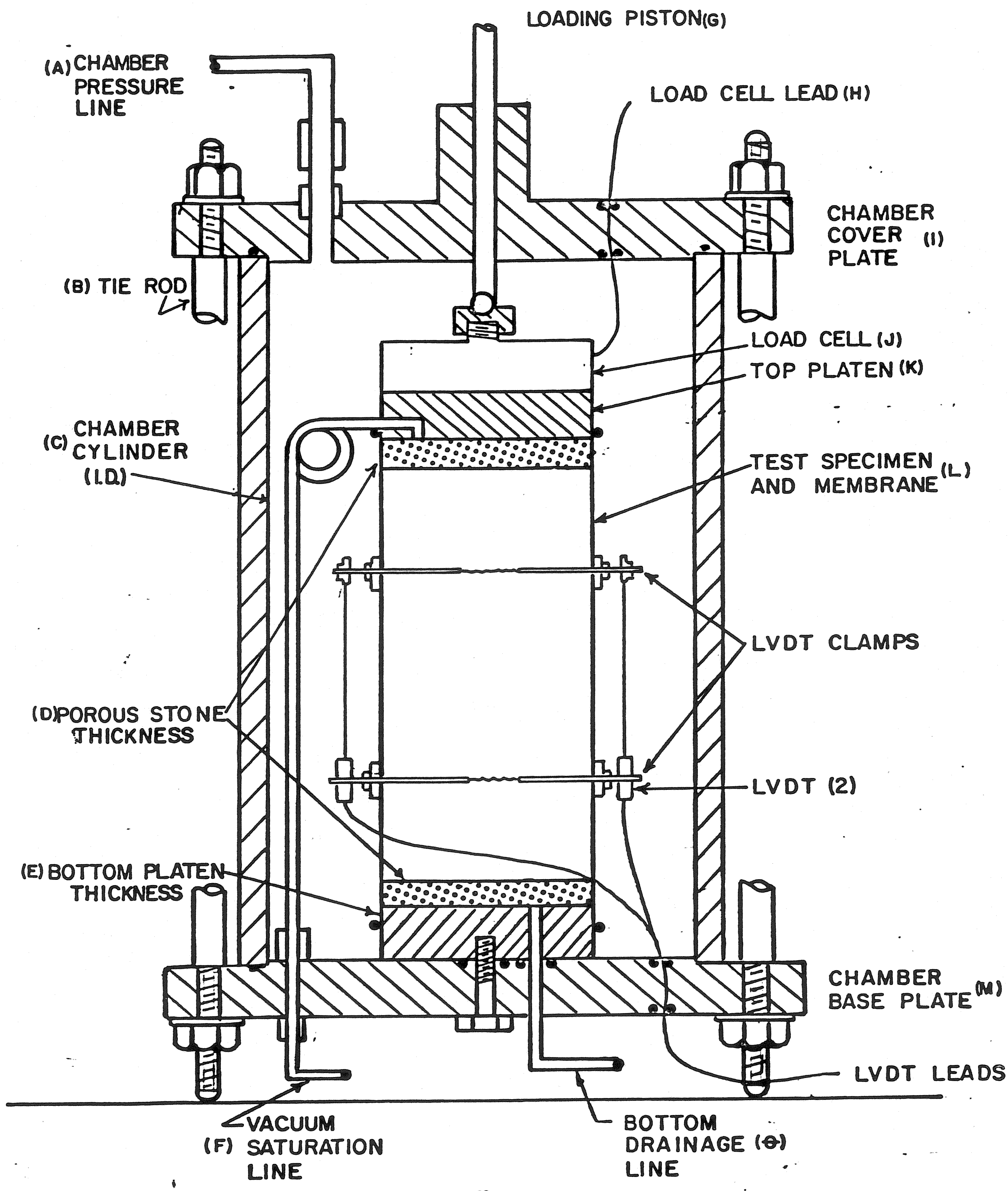


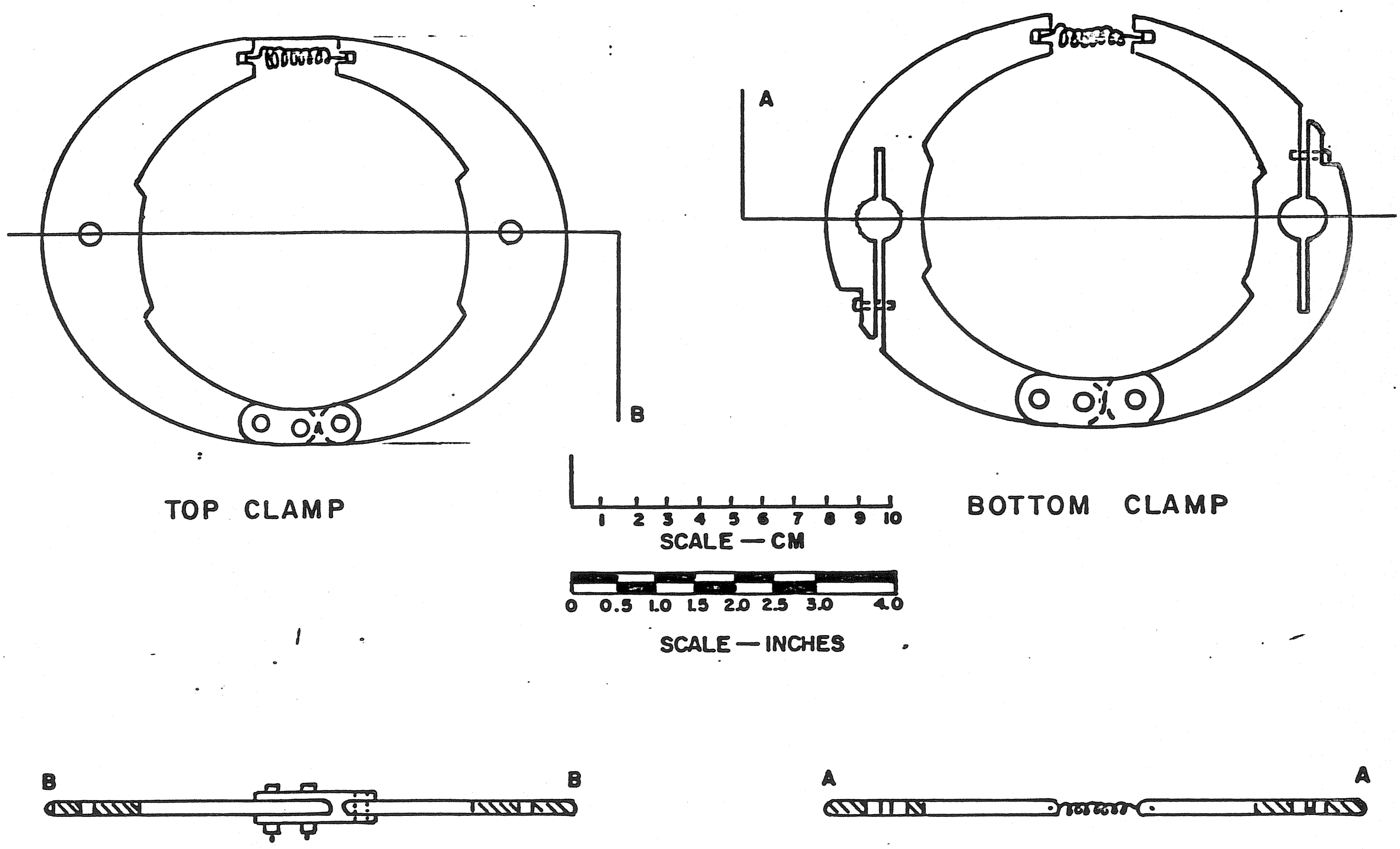
TABLE OF MEASUREMENTS (TYPICAL)

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
METRIC, mm.	6.4	12.7	152.4	6.4	38.1	6.4	12.7	Note 1	19.1	Note 1	38.1	Note 2	25.4	6.4	
ENGLISH in.	0.25	0.50	6.00	0.25	1.50	0.25	0.50		0.75		1.50		1.0	0.25	

NOTE:
1. Dimensions varies with manufacturer

Figure 1

LVDT CLAMP DETAIL



NOTE: Dimensions very with manufacturer and specimen size

Figure 2

TRIAXIAL CHAMBER WITH EXTERNAL LVDT'S AND LOAD CELL

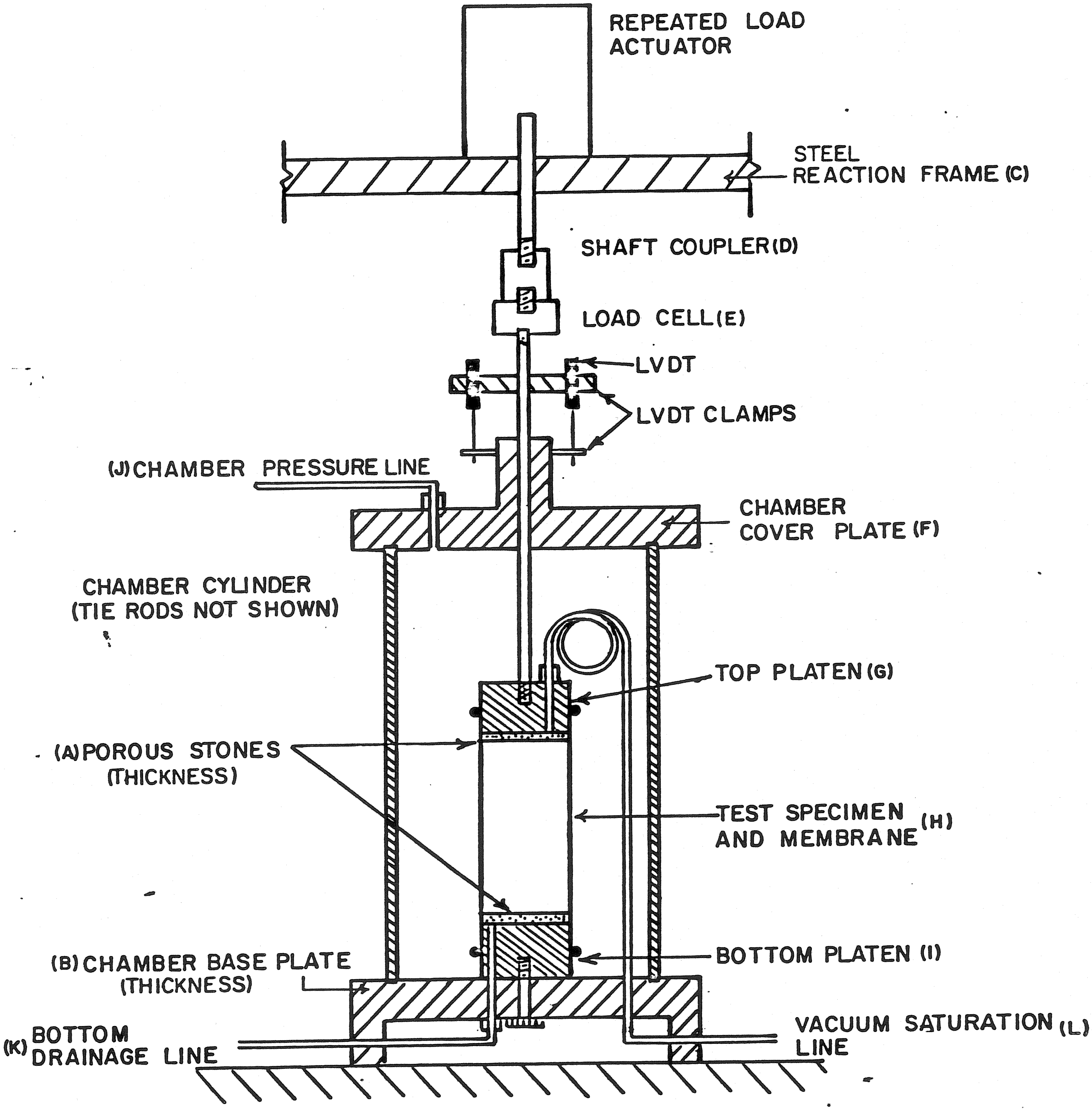


TABLE OF MEASUREMENTS (TYPICAL)

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L
METRIC, mm.	6.4	25.4	12.7	25.4	Note 1	19.1	38.1	Note 2	38.1	6.4	6.4	6.4
ENGLISH in	0.25	1.00	0.5	1.00		0.75	1.50		1.50	0.25	0.25	0.25

1. Dimension varies with manufacturer
2. Dimension varies with specimen size

Figure 3

PROVING-RING CALIBRATION DEVICE

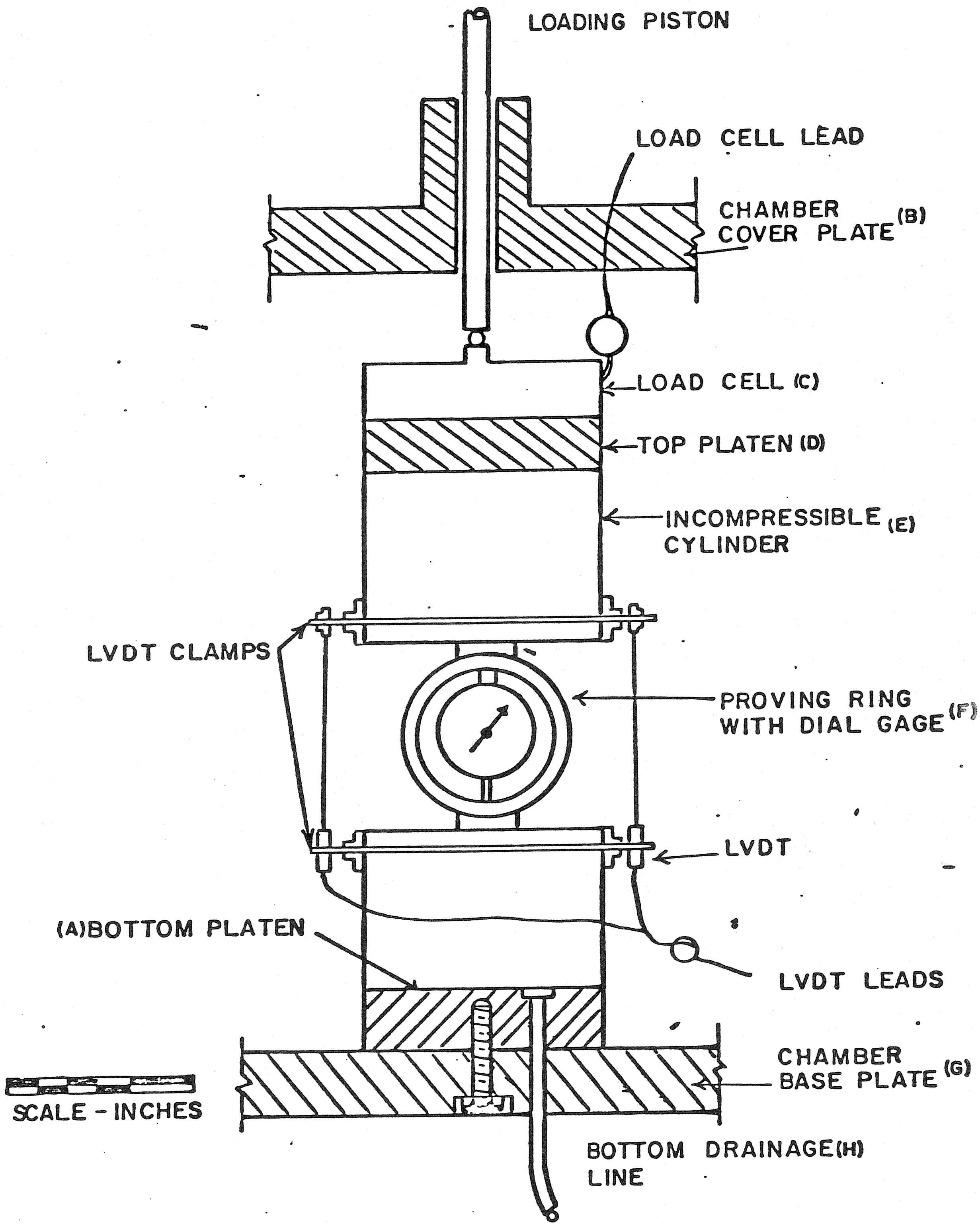


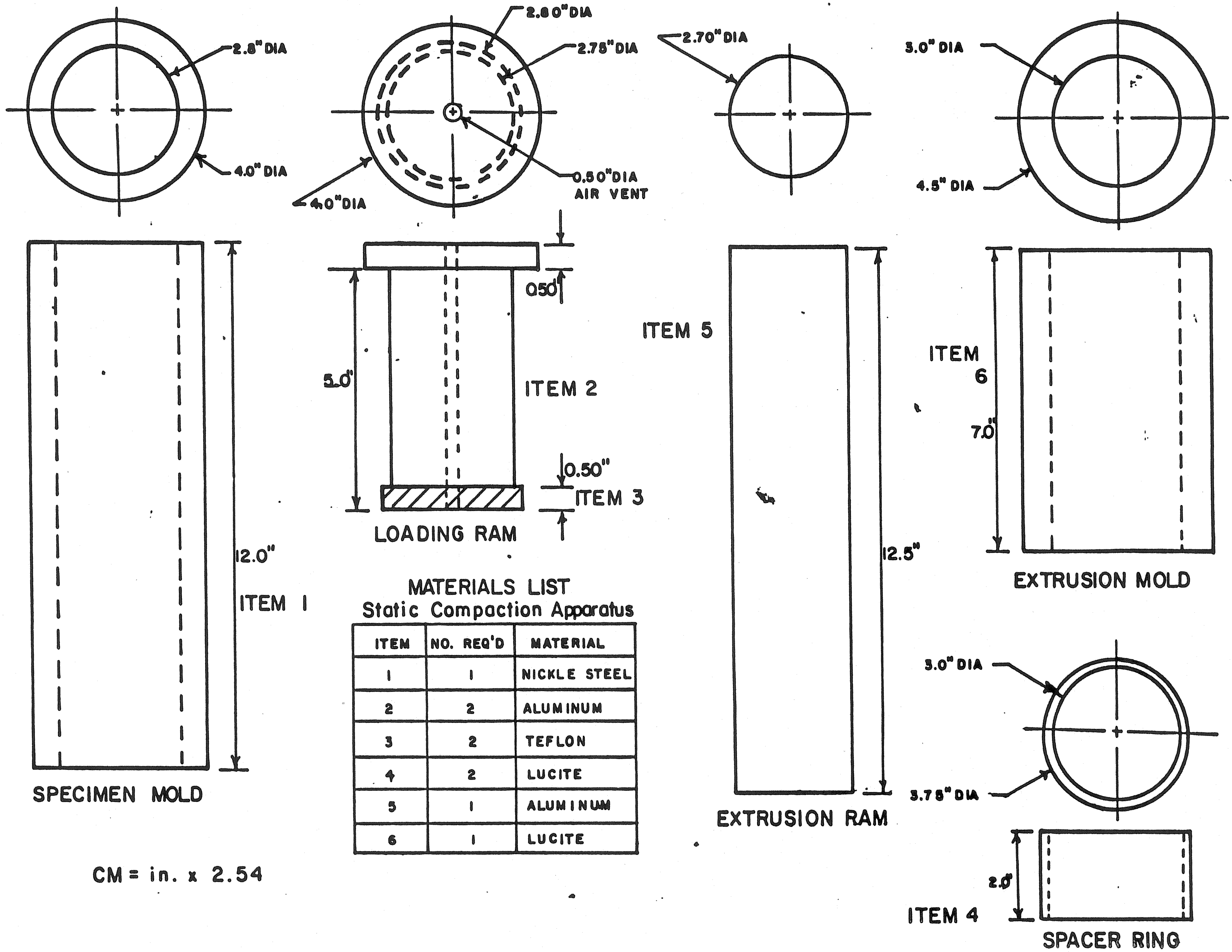
TABLE OF MEASUREMENTS (TYPICAL)

DIMENSION	A	B	C	D	E	F	G	H
METRIC mm	38.1	19.1	Note 1	38.1	Note 1	Note 1	25.4	6.4
ENGLISH in	1.50	0.75		1.50			1.0	0.25

1. Dimension varies with specimen size & equipment manufacturer

Figure 4

APPARATUS FOR STATIC COMPACTION



MATERIALS LIST
Static Compaction Apparatus

ITEM	NO. REQ'D	MATERIAL
1	1	NICKLE STEEL
2	2	ALUMINUM
3	2	TEFLON
4	2	LUCITE
5	1	ALUMINUM
6	1	LUCITE

CM = in. x 2.54

Figure 5

APPARATUS FOR VIBRATORY COMPACTION OF COHESIONLESS SOILS

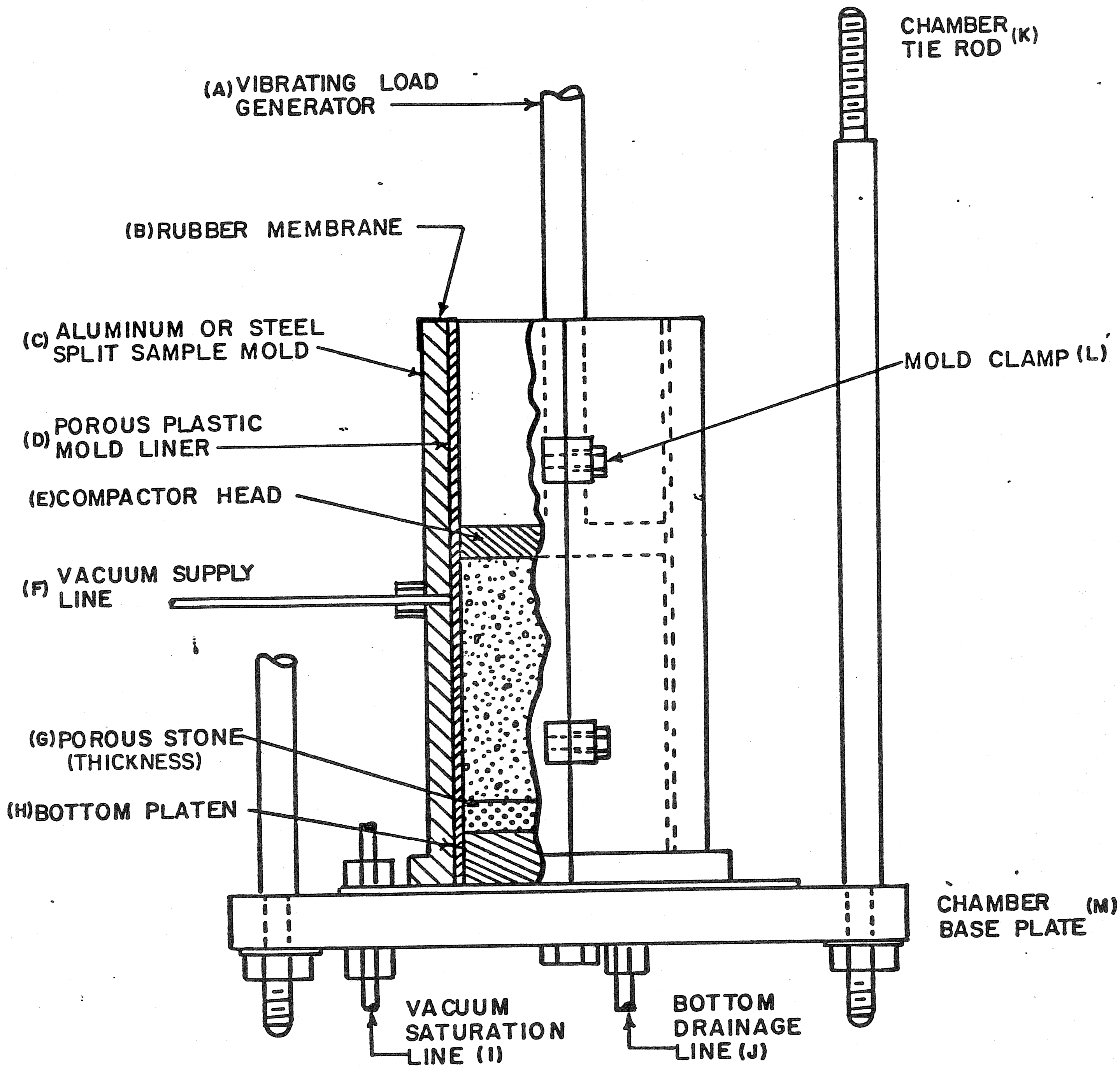


TABLE OF MEASUREMENTS (TYPICAL)

DIMENSION	A	B	C	D	E	F	G	H	I	J	K	L	M
METRIC, mm.	Note 1	Note 2	Note 2	Note 2	Note 3	6.4	6.4	38.1	6.4	6.4	12.7	Note 1	25.4
ENGLISH, in.						0.25	0.25	1.50	0.25	0.25	0.50		1.00

NOTE:

1. Dimension varies with manufacturer
2. Dimension varies with specimen size
3. Diameter should be 0.25 ± 0.02 inch (6.35 ± 0.5 mm) smaller then specimen diameter

Figure 6

Soil Sample ________	Soil Specimen Weight	Date ________
Location ________	Initial Wt. of Container	Compaction Method ________
Sample No. ________	+Wet Soil-gms. ________	*Vertical Spacing Between
Specific Gravity ________	Final Wt. of Container	LVDT Clamps-in.(cm) ________
	+Wet Soil-gms. ________	
Soil Specimen Measurements	Wt. Wet Soil Used ________	Constants
Diameter Top ________		Vertical LVDT ________
Middle ________	Soil Specimen Volume	Load Cell ________
Bottom ________	Initial Area A_o	
Average ________	$in^2 (cm^2)$ ________	Water Content After
Membrane Thickness ________	Volume $A_o L_o$	Resilience Testing % ________
Net Diameter ________	$in^3 (cm^3)$ ________	Comments ________
Ht Specimen + Cap + Base ________	Wet Density-pcf(kN/m^3) ________	________
Ht Cap + Base ________	Compaction Water Content, w_c, % ________	________
Initial Length, L_o ________	% Saturation ________	________
	Dry Density-pcf(kg/m^3) ________	________

Nominal Deviator Stress σ_d psi (kPa)	Chamber Pressure σ_3 psi (kPa)	Load Cell Chart Reading	Deviator Load lb (kN)	Applied σ_d psi (kPa)	Recoverable Deformation LVDT Chart Reading		Recoverable Deformation Inches (mm)	ϵ_r in/in (mm/mm)	$M_r = \sigma_d/\epsilon_r$ psi (kPa)
					S				

*Not applicable for externally mounted LVDT's.

Figure 7. Form for Resilient Modulus Tests on Cohesive Soils

Nominal Deviator Stress σ_d psi (kPa)	Chamber Pressure σ_3 psi (kPa)	Load Cell Chart Reading S	Deviator Load lb (kN)	Applied σ_d psi (kPa)	Recoverable Deformation LVDT Chart Reading S	Recoverable Deformation Inches (mm)	ϵ_r in/in (mm/mm)	$M_r = \sigma_d/\epsilon_r$ psi (kPa)

Soil Sample ______
Location ______
Sample No. ______
Specific Gravity ______

Soil Specimen Measurements

Diameter
- Top ______
- Middle ______
- Bottom ______
- Average ______

Membrane Thickness ______
Net Diameter ______
Ht Specimen + Cap + Base ______
Ht Cap + Base ______
Initial Length, L_o ______
Inside Diameter of Mold ______

Soil Specimen Weight
Initial Wt. of Container
+Wet Soil-gms. ______
Final Wt. of Container
+Wet Soil-gms. ______
Wt. Wet Soil Used ______

Soil Specimen Volume
Initial Area A_o
$in^2 (cm^2)$ ______
Volume $A_o L_o$
$in^3 (cm^3)$ ______
Wet Density-pcf(kN/m^3) ______
Compaction Water Content, w_c, % ______
% Saturation ______
Dry Density-pcf(kg/m^3) ______

Date ______
Compaction Method ______
*Vertical Spacing Between
LVDT Clamps-in.(cm) ______

Constants
Vertical LVDT ______
Load Cell ______

Water Content After
Resilience Testing % ______
Comments ______
______
______
______
______

Chamber Pressure σ_3 psi (kPa)	Nominal σ_d psi (kPa)	Load Cell Chart Reading	Deviator Load lb (kN)	σ_d psi (kPa)	σ_1 psi (kPa)	Recoverable Deformation LVDT Chart Reading	Recoverable Deformation inches (mm)	ϵ_r in/in mm/mm	$M_r = \sigma_d/\epsilon_r$ psi (kPa)	$\theta = \sigma_1 + 2\sigma_3$ psi (kPa)

*Not applicable for externally mounted LVDT's.

Figure 8. Form for Resilient Modulus Tests on Granular Soils

Granular Soil-Continuation Sheet

Sample No.________________

Date________________

Chamber Pressure σ_3 psi (kPa)	Nominal σ_d psi (kPa)	Load Cell Chart Reading	Deviator Load lb (kN)	σ_d psi (kPa)	σ_1 psi (kPa)	Recoverable Deformation LVDT Chart Reading	Recoverable Deformation inches (mm)	ϵ_r in/in mm/mm	$M_r = \sigma_d/\epsilon_r$ psi (kPa)	$\theta = \sigma_1 + 2\sigma_3$ psi (kPa)

COMPACTED SOIL SPECIMEN DATA SHEET

Specimen No.__________________ Date______________________________

Soil____

Desired dry unit weight, pcf ______________ Desired w, % __________________

<u>Specimen dimensions</u>:

Length, L_s, in. ______________ diameter, in. _________________________

Area, in.^{2} ____________________ volume, in.^{3} ____________ ft^3 ___________

Specimen weights: Dry solids, W_s, lbs _____________, g __________________

Water, W_w, lbs __________________, g __________________

$W_{Ts} = W_s + W_w$, lbs ____________________, g __________________

<u>Soil Mix Weights</u>: air dry water content, W_{ad}, % __________________________

Solids + 500 g = W_s + 500 _________________g

$W_T = (W_s + 500)(1 + w_{ad}/100)$ __________________g

Final $W_w = w(W_s + 500)$ _________________g

Air dry $W_{w_{ad}} = w_{ad}(W_s + 500)$ _________________g

Added water = Final $W_w - W_{w_{ad}}$ _________________g

Final weights: W_T + Added Water __________________g

tare __________________g

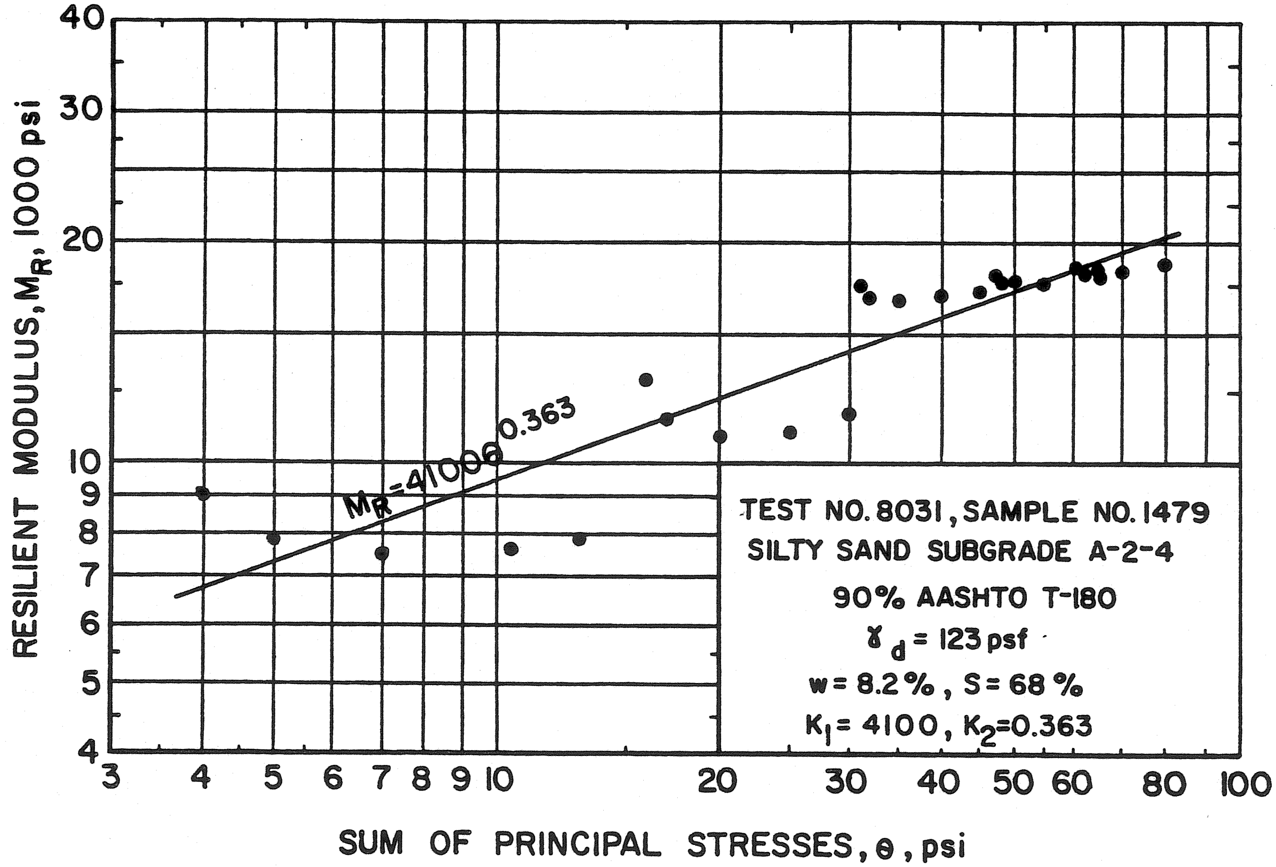
Total final mix weight ____________________________g

<u>Specimen Compaction Weights</u>: (Number Required)

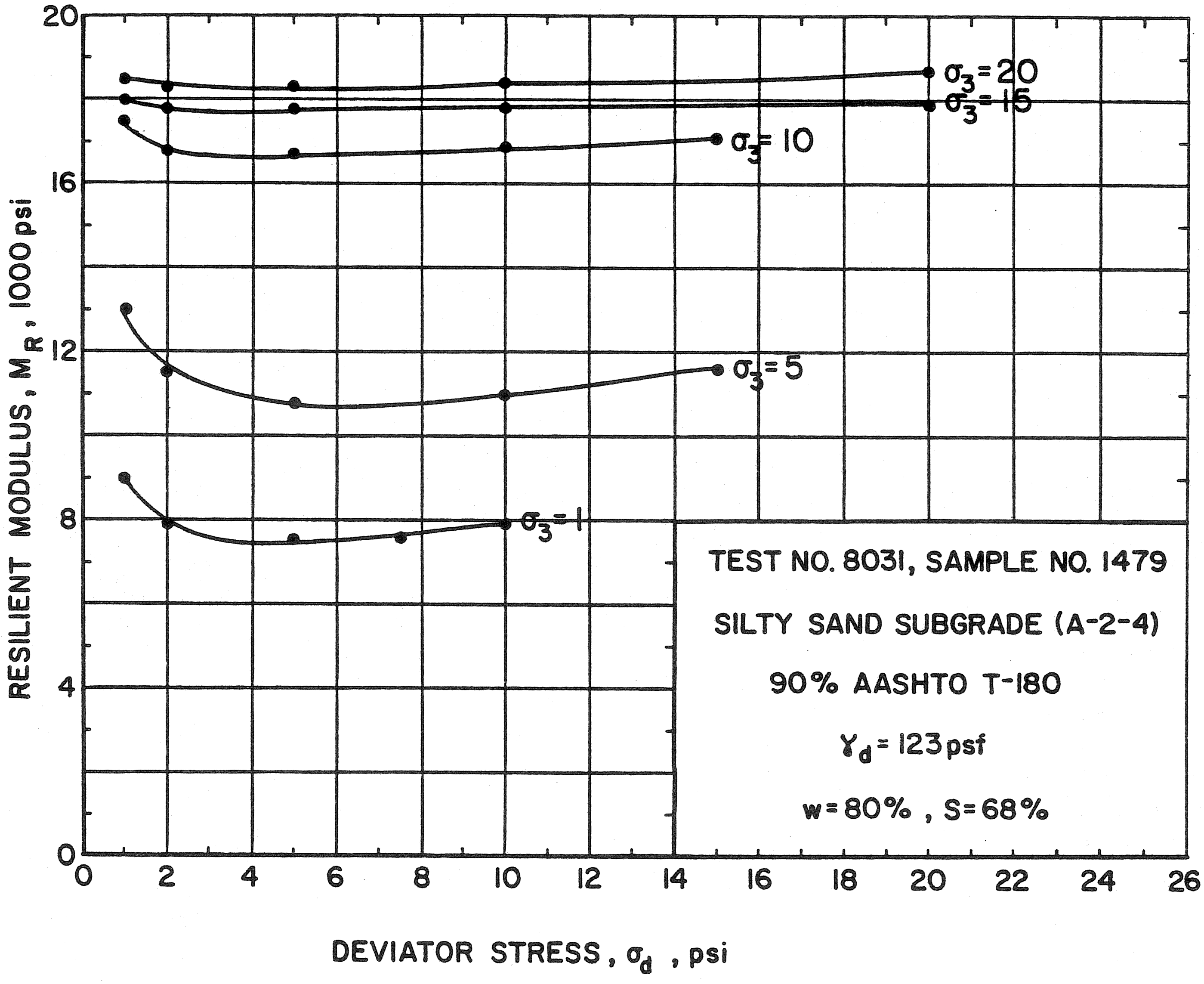
$W_{L_1} = W_{Ts} \cdot \frac{L_1}{L_s}$ = _____________________ = ___________________g ___________

$W_{L_2} = W_{Ts} \cdot \frac{L_2}{L_s}$ = _____________________ = ___________________g ___________

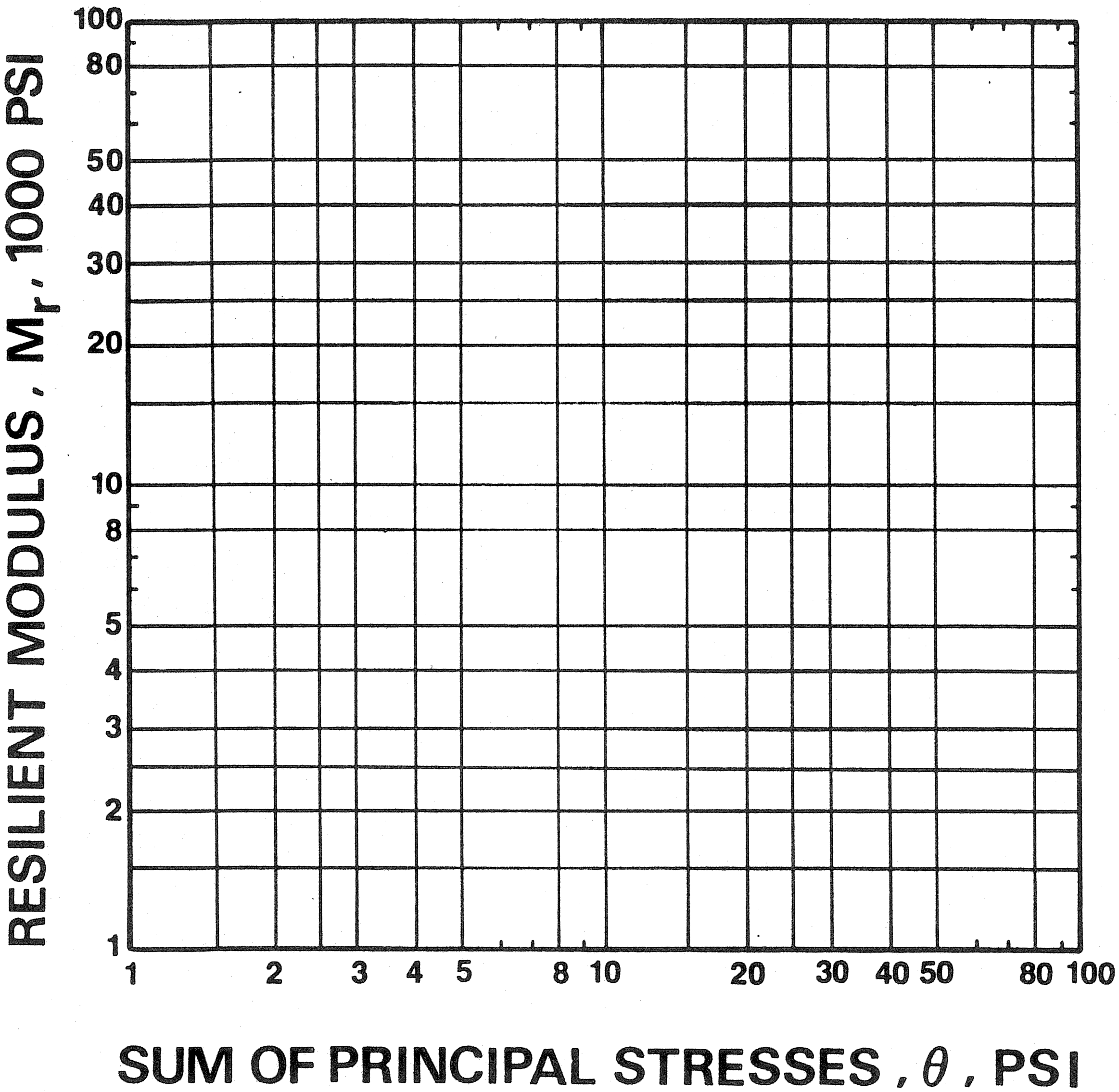
$W_{L_3} = W_{Ts} \cdot \frac{L_3}{L_s}$ = _____________________ = ___________________g ___________



RESILIENT MODULUS, M_R, 1000 psi
SUM OF PRINCIPAL STRESSES, θ, psi
$M_R = 4100\theta^{0.363}$
TEST NO. 8031, SAMPLE NO. 1479
SILTY SAND SUBGRADE A-2-4
90% AASHTO T-180
γ_d = 123 psf
w = 8.2%, S = 68%
K_1 = 4100, K_2 = 0.363
40
30
20
10
9
8
7
6
5
4
3
4
5
6
7
8
9
10
20
30
40
50
60
80
100



RESILIENT MODULUS, M_R, 1000 psi
DEVIATOR STRESS, σ_d, psi
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
4
8
12
16
20
$\sigma_3 = 20$
$\sigma_3 = 15$
$\sigma_3 = 10$
$\sigma_3 = 5$
$\sigma_3 = 1$
TEST NO. 8031, SAMPLE NO. 1479
SILTY SAND SUBGRADE (A-2-4)
90% AASHTO T-180
γ_d = 123 psf
w = 80%, S = 68%



RESILIENT MODULUS, M_r, 1000 PSI
100
80
50
40
30
20
10
8
5
4
3
2
1
1
2
3
4
5
8
10
20
30
40
50
80
100
SUM OF PRINCIPAL STRESSES, θ, PSI

APPENDIX B

Summary of Operating Instructions

for

Retsina Mark III Resilient Modulus Device

SUMMARY OF OPERATING INSTRUCTIONS FOR
RETSINA MARK III RESILIENT MODULUS DEVICE

1. Theory

In a general way, the elastic modulus of a material is defined as:

$$\text{Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

where the duration of loading does not change the value obtained. For a linear viscoelastic material such as asphalt concrete the same relationship is used. However the conditions of the test must be defined because short loading periods can give much higher modulus values than long loading periods. This is because more time allows more flow or deformation to occur. Moduli that are time-dependent are referred to as Resilient Moduli or as Stiffness Moduli. Frequently moduli determined at very long loading times are referred to as Creep Moduli. Temperature also effects modulus. Therefore, resilient modulus is reported at a given temperature as well as a given rate of loading.

Operating Principle

The Mark III Resilient Modulus (M_R) device functions by applying a 0.1 - second load pulse once every three seconds diametrally across the vertical diameter of a cylindrical specimen and sensing the resultant deformation across the horizontal diameter. The specimen can have a diameter from 3 1/2 inches to 4 inches and a thickness of 1 to 3 inches. Optimum specimen diameter is 4 inches, and optimum thickness is 2 1/2 inches (e.g. Hveem specimen). Loads used vary from 10 lb. to 75 lb. Low strength specimens require the use of low loads so that their linear limit stress is not exceeded; the loading, therefore, is not destructive. Specimen deformations range from 1 to 2000 microinches.

Diametral loading (application of a load across the 4.00" vertical diameter of the cylinder) results in a deformation across the horizontal diameter. The vertical load, p, and the horizontal deformation (Δ) are related to the Resilient Modulus (M_R), Poissons ratio (ν), and specimen thickness (t) as follows:

$$M_R = \frac{p(\nu + 0.2734)}{t\,\Delta}$$

If p is in pounds and t and Δ are in inches in the above equation, the units of M_R will be psi.

Thus by measuring the thickness of the specimen and the deformation resulting from a known pulsating load, the Resilient Modulus or M_R can be calculated. A Poissons ratio of 0.35 has been shown to be a reasonable value to use in the calculation for sound asphalt-treated materials.

2. Set-up

A. Place the yoke on the alignment stand. Do not remove the protective hoods from the transducer until specimen is prepared. Before placing the specimen in the alignment stand, smooth the areas the transducers will touch with a knife or emery cloth, being sure to wipe dust from the contact area. Remove protective hood from transducers making sure the tips are withdrawn into the transducer's barrel. Carefully place the specimen into the alignment stand with the prepared areas in line with the transducers. Being careful the specimen is straight and not touching the edges of yoke, tighten the four (4) screws securing the specimen to the yoke. Make sure the specimen is aligned correctly and tightly secured to the yoke.

B. Remove specimen, transducers and yoke from alignment stand by grasping the specimen and not the yoke or transducers. Place the specimen's bottom edge along the curved rubber pad's long axis. Position the specimen such that the line of axis of the transducers is parallel to the base of the device and perpendicular to the loading axis. Place rubber lined loading plate across the specimen such that it is directly above the lower rubber pad and the loading ball is centered in the loading head of the Bellofram. Make sure:

1. The ball is centered in the loading head of the Bellofram.
2. The top and bottom rubber pads are directly across from each other in line with the loading axis.
3. The transducer's are parallel to the base of the device and perpendicular to the loading axis.
4. Both top and bottom rubber pads cover entire width of specimen.

C. Connect electrical leads of transducers into back of control box making sure the transducer leads are in the correct spots. Turn Mode knob to Setup, Function knob to M_R and Multiplier knob to 200. Using zero control, set needle at 1/10 full scale, for "base reading." Slowly turn transducer adjustment screw clockwise so tip moves toward specimen. Watch needle for point of contact and adjust so that the needle is at 1/10 full scale above the "base reading." Watch carefully for needle movement toward "base reading." Keep adjusting transducer adjustment screw so reading remains 1/10 full scale above "base reading" (until needle does not move). This reading (2 - 1/10 full scale readings) is the new "base reading" for the second transducer adjustment. Repeat procedure for second transducer. End reading should be 3 - 1/10 full scale readings.

D. Check the transducers' contact by screwing the transducers' adjustment screws counterclockwise one at a time. Note the reduction of the needle reading for each transducer. It should be 1/10 full sclae reading for each transducer so that needle should return to the "base reading" for each transducer. If it does not, repeat procedure C.

E. When readings return to "base reading" in procedure D, return transducer tips to specimen as in procedure C. The assembly is now ready for testing.

3. Testing

Determine load to be used for testing such that the load is within the linear elastic range of the specimen. Enter Figure 1* with the desired load and loading type to read off the required air pressure to be used in testing. Turn Function knob to a suitable psi multiplier and adjust air pressure by the regulator valve. Check to see loading type switch is in correct position then turn Mode knob to operate. The pressure will fluctuate slightly so readjust the air pressure regulator until the desired pressure occurs at the peak value of needle fluctuation. Record the air pressure.

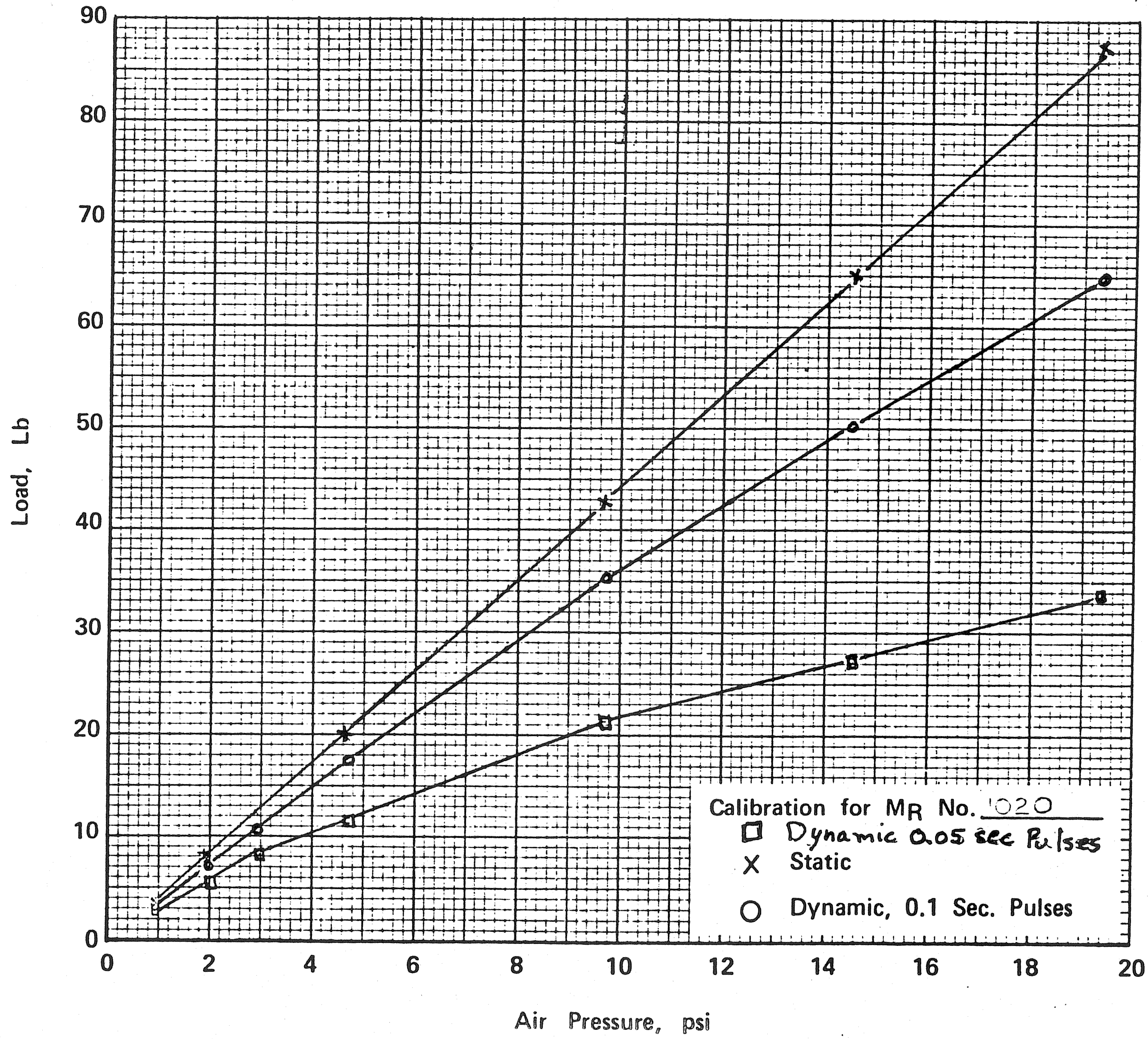
Switch Function knob to M_R and adjust Multiplier knob and Zero knob to get reading within range of Mark III readout. With each pulse, the needle will

---

*Note: Figure 1 is unique for each set of equipment. Use the "Figure 1" calibration supplied by manufacturer with subsequent calibration adjustments to the Figure as the need arises.

FIGURE 1.

CALIBRATION OF LOAD
DELIVERED BY BELLOFRAM ON
RESILIENT MODULUS DEVICE



fluctuate from a stable point. The deformation indicated is the value of needle movement increased by the Multiplier.** Record deformation (average of several pulse loadings).

If at any time during the operation in the Operate mode the zero setting drops too low because of creep or yoke movement, the zero low indicator light emitting diode (LED) will glow. Turn the Zero control knob clockwise until the glow extinguishes. If high LED glows turn the Zero adjustment counter-clockwise until glow disappears. During operation both LED's should be out.

At conclusion of testing return Function knob to Setup and Multiplier to 200. One at a time retract transducers from specimen and note needle movement due to each transducer. This should correspond to the set needle movement (1/10 full scale) of the test set-up procedure. If it does not the testing is not valid and must be repeated.

Enter load and deformation into M_R equation to calculate specimen's resilient modulus for the mode of loading used. The entire procedure should now be repeated for the same specimen after being rotated 90°. The average of the two tests will give the appropriate resilient modulus for the specimen under the testing mode and temperature.

**Note: Recent Retsina models have digital readout in lieu of the needle readout of the Mark III model.

RESILIENT MODULUS OF ASPHALT CONCRETE (4 inch diameter specimens)

Specimen		Test Temp., °F	Applied Load, P, lbs.	Horizontal Deformation, microinches			$M_R = \frac{0.61 \times P}{t \times Defmn} \times 10^6$ psi
Ident. Number	Thickness t, inches			Needle Movement x Multiplier No.=Defmn.			

FACTORS AFFECTING RESILIENT MODULUS OF ASPHALT CONCRETE AND THEIR PRACTICAL IMPLICATIONS

The test equipment arranged in this project and described in this report has the ability to measure resilient modulus of asphalt concrete in compression and in diametral tension. In fact, similar equipment is used in various highway materials laboratories in the United States.

Resilient modulus obtained in the compression mode on cylindrical specimens, e.g. 4 in. dia. X 8 in. high, would appear to give a fair representation of the compressive flexural modulus and the vertical compressive stress modulus in asphalt concrete layers. Resilient modulus obtained diametrally in the tensile mode (indirect) on cylindrical specimens, e.g. 4 in. dia. X 2.5 in. long, would appear to give a fair representation of the tensile flexural modulus in cohesive asphalt concrete layers. Evidence shows that the diametral tensile modulus also reflects damage in the asphalt concrete because it is in the flexural, tensile zone where most cracks and disintegration progresses from adhesion and cohesion failure. In either case of modulus measurement, however, the modulus obtained should suffice for pavement design purposes providing the strains imposed during the test are small and are produced within the working stress of the field conditions. One should keep in mind that, on the average, the tensile modulus will be lower.

Effect of Loading Rate and Temperature

Characteristic of every viscoelastic material is the modulus dependency on rate of loading and temperature. Asphalt concrete is no exception.

Therefore it is necessary to perform the test at the prescribed field conditions if the modulus value obtained is to be used for predictive performance of pavements.

Modern air pressure-electric controlled valve units such as the Bellofram produce rates of loading similar to those that are experienced in pavements. Another advantage is that the load pulse simulates the field mode due to the rolling wheels, an important consideration when testing viscoelastic materials. Currently the Bellofram units respond satisfactorily with the 0.10 sec. load pulse and seem to have the capability of producing the 0.05 sec. load pulse for fast-moving traffic. The limitations of accurate recording of the 0.05 sec. load pulse deformation response are due to equipment frame deflections and vibrations and to slow response characteristics of some recording equipment. This is why most of the resilient modulus testing is performed with the 0.10 sec. load pulse. The modulus at 0.10 sec. is lower than the modulus at 0.05 sec. For some asphalt concretes, the modulus is essentially equal at both loading rates.

Since most climates have significant air temperature differences throughout the annual seasons, then the asphalt concrete modulus in the field will also show differences. A summer modulus of 200,000 psi and a winter modulus of 1,500,000 psi may not be too uncommon in areas of Idaho. An accurate assessment of pavement performance will entail the use of several modulus values, e.g. four values, to represent the annual seasons. Most of the time the modulus is calculated at laboratory test temperatures of 72°F or 77°F because it is a convenient laboratory temperature. If this temperature represents the seasonal mean temperature for a field location, then the use of this room-temperature modulus isn't so bad for a general season-averaging approach. But the test temperature could be too high or too low for other locations.

Water

Evidence is conclusive that wet asphalt concrete has a different modulus than dry asphalt concrete. A pavement under first-time wetness without experiencing the effects of freeze-thaw or hot-damp cycles can have a decrease or an increase of modulus depending on its basic moisture sensitivity. When environmental conditions and traffic effects build-up, the moisture-sensitive asphalt concretes lose modulus (become less stiff). The equipment arranged in this project can measure all these effects on properly prepared test specimens.

All evidence so far points to the future practical use of modulus change to show related strength changes in asphalt concrete as well as using modulus in stress-strain evaluation of pavements. Changes of resilient modulus, increase or decrease, are proportional (more or less) to the corresponding changes of splitting tensile strength and fatigue life (in the pavement stress-strain range). For instance, if the modulus significantly decreases due to water, one can expect the fatigue life of the asphalt concrete pavements to significantly decrease also, and that a reduced substitution ratio should be assigned to the asphalt concrete after a few years in the field.

If the influence of water decreases the modulus, mechanistic pavement analysis shows that the bending strain in the asphalt concrete will increase for a given pavement thickness. The pavement fatigue life will decrease due to this effect alone. Unfortunately, the asphalt concrete's fatigue life curve will also be worse (as compared to its dry curve), leading then to a more significant decrease of fatigue life.

Asphalt Aging

Asphalt will age-harden more rapidly in high-void asphalt concrete pavements. Limited field data show average modulus increases of 1.5 or so over a period of a few years. Different asphalts have different aging rates. Modulus increase ratios can be as low as 1.0 to as high as 6.0. Unfortunately, the asphalt concrete is losing its ductility or plasticity in the field. This produces more rapid crack propagation in the embrittled asphalt leading to faster losses of pavements serviceability because of developed surface cracking.

The modulus testing of laboratory fabricated test specimens with and without rolling thin-film aged asphalt, for example, may predict the increased field modulus ratio. Mechanistic pavement analysis should show reduced life when combining the greater modulus with the lowered position of the asphalt-aged fatigue life curve.

Poisson's Ratio

Trends of laboratory data indicate that Poisson's ratio increases with: (a) moisture in moisture-sensitive asphalt concrete, (b) temperature, and (c) loading time. It can be as low as 0.20 and as high as 0.45 or so. Usually a value of 0.33 is used. For most situations involving the practical applications of mechanistic analysis the value of 0.33 gives reasonable accuracy. Specimen collars holding LVDT's in perpendicular positions, when performing the compressive, resilient modulus test, can be used to calculate the Poisson's ratio from both LVDT measurements.

Low Strength Mixtures

The resilient modulus of low-strength mixtures, such as non-fully-cured emulsion mixes or open-graded emulsion mixes, cannot be calculated easily without employing confining pressure during testing. Compressive modulus testing uses the direct air confining pressure method against the sides of the specimen in a triaxial cell. Diametral tensile modulus testing uses two end plates with a rubber sleeve; confinement is produced through vacuum suction of air from the inside of the specimens through the end plates. The FHWA laboratory in Vancouver, WA, uses such a device with satisfactory results.

Mechanistic Pavement Design and Analysis

Resilient modulus and Poisson's ratio are the only asphalt concrete mechanical parameters used in the computation for stresses, strains and displacement. For a given pavement section (thickness, number of layers, subgrade support), the modulus determines the magnitude of the critical bending stress and strain. Therefore, the laboratory modulus test on asphalt concrete specimens representing field conditions is necessary. The field bending stress and strain, calculated from the resilient modulus, are then used with the splitting tensile strength and stress-strain fatigue life curves of the asphalt concrete represented for purposes of predicting fatigue life of the pavement layer. As this method becomes more widely used, perhaps with the intermediate step of correlation to substitution ratios, one will find that resilient modulus testing will become a standard operating test procedure. Durable and accurate test equipment will be necessary. The equipment arranged in this project represents the best choice of currently proven technology in this regard.